Teaching material

Course No. AEZ 121
Course Title: Fundamentals of Entomology
Credit hr. 4(3+1)
Semester II

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Course content and break up

Theory

Sl.No.	Lecture-wise course content	No.of Lectures
1.	History of Entomology in India	1
2.	Dominance of insects, intrinsic factors like structural perfections, developmental characteristics, high fecundity, food specificity, protective adaptations and devices, chemical communication and other factors	1
3.	Classification of phylum- Arthropoda up to classes and relationship of class Insecta with other classes of Arthropoda	1
4.	Morphology ; structure and functions of insect cuticle and moulting	2
5.	Body segmentation, structure of head, thorax and abdomen	2
6.	Structure and modifications of insect antennae, mouth parts and legs	3
7.	Wing venation, wing coupling apparatus and its modifications	2
8.	Structure of male and female genitalia	1
9.	Metamorphosis and diapauses in insects	2
10.	Sensory organs, mechano, chemo and photoreceptors(ocelli and compound eye)	2
11.	Types of larvae and pupae	2
12.	Structure and functions of digestive system in insects	1
13.	Excretory system in insects	1
14.	Circulatory system in insects	1
15.	Respiratory system in insects	1
16.	Nervous system in insects	1
17.	Reproductive system in insects	2
18.	Types of reproduction in insects	1
19.	Secretary (Endocrine) system	1
20.	Insect Ecology: Introduction,environment and its components	1
21.	Effect of abiotic factors:temperature, humidity,rainfall,lightatmospheric pressure and air currents on insect population	1
22.	Effect of biotic factors:food,competition,natural enemies and environmental resistance	1
23.	Categories of Pests	1
24.	IPM: importance, concept, practices, scope and limitations of IPM	2
25.	Classification of insecticides	1
26.	Toxicity of insecticides and formulations of insecticides	1
27.	Chemical control, importance, hazards and limitations	2
28.	Recent methods of pest control, repellents, antifeedants, hormones, attractants, Gamma Radiation	2
29.	Insecticides Act 1968-Important provisions	1
30.	Application techniques of spray fluids	1
31.	Symptoms of poisoning, first aid and antidotes	1
32.	Taxonomy: Importance,history, binomial nomenclature, definition of species, subspecies, biotype, genus, family, order	2
33.	Classification of class Insecta up to order	1
34.	Insect families: - distinguished characters and important example: Orthroptera: Acrididae,Tettigonidae, Gryllidae, Gryllotalpidae; Dictyoptera:Mantidae, Blattidae; Odonata; Isoptera:Termitidae;	9

	Thysanoptera:Thripidae; Hemiptera: Pentatomidae, Coreidae,Cimicidae Pyrrhocoridae,Lygadae, Cicadellidae, Delphacidae, Aphididae, Coccidae, 'Lophophidae,Aleurodidae, Pseudococcidae; Neuroptera: Chrysopidae; Lepidoptera: Pieridae,Papilionidae, Noctuidae, Sphingidae, Pyralidae, Gelechiidae, Arctiidae, Saturnidae, Bombycidae; Coleoptera: Coccinellidae, Chrysomelidae, Cerambycidae, Curculionidae, Bruchidae, Scarabaeidae; Hymenoptera: Tenthrinidae, Apidae, Trichgrammatidae, Ichneumonidae, Braconidae, Chalcidae; Diptera: Cecidomyiidae, Tephritidae, Tachinidae, Agromyzidae,Culicidae, Muscidae)	
	Total lectures	55

Practical

S.No.	Topics	No. Of Practical classes
1.	Methods of collection and preservation of insects including immature stages	1
2.	External features of grasshopper/Blister beetle	1
3.	Types of antenna	1
4.	Types of mouth parts and legs	1
5.	Types of wing and venation	1
6.	Types of larvae and pupa	1
7.	Dissection of Digestive system	1
8.	Dissection of Male and female reproductive system	1
9.	Study of Characters of orders Othoptera, Dictyoptera, odonata, Isoptera, Thysanoptera, Hemiptera, Lepidoptera, Neuroptera, Coleoptera, Hymenoptera, Diptera and their families	7
10.	Study of Insecticides and their formulations.	1
11.	Pesticide appliances and their maintenance	1
12.	Sampling techniques for estimation of insect population and damage	1
	Total classes	18

References

1. Insecta an Introduction – K.N. Ragumoorthi, V. Balasubramani, M.R. Srinivasan and N.Natrajan
2. An Introduction to Entomology – P. D. Srivastava and R. P. Singh
3. Itroduction to General and Applied Entomology – V. B. Awasthi
4. Elements of Insect Ecology - Yazdani and Agarwal
5. Applied Entomology- K.N.Ragumoorthi, V. Balasubramani, M.R. Srinivasan and N.Natarajan.2006.A.E. Publication.
6. Agricultural Pests of south Asia and their management.Kalyani Publishers, New Delhi- A.S.Atwal and G.S. Dhaliwal.2005.

AEZ 121 Fundamentals of Entomology (3+1)

Part- I

History of Entomology in India

Entomology is a biological science dealing with a specific group of organisms, the insects. The word Entomology is of greek origin. Gr. Entomon – insect and gr. Logia – discourse. Thus , the entomology is science to discourse on insect.

Insects are tracheate arthropods with distinct head, thorax and abdomen, a single pair of antenna, three pairs of legs and one or two pairs of wings.

1758 – The beginning of the modern era of Indian Entomology came with the publication of the tenth edition of Carl Linnaeus's "Systema Naturae". This contained the eariliest record of 28 species of Indian insects.

The first entomologist who made an extensive study of Indian insects was **J.C.Fabricius**. He (Danish Professor of political economy) had classified the insects into 13 orders based on type of mouth parts.

1901 – Lionel de Nicevelle was posted as the first entomologist to the Government of India.

1903 – Prof. Maxwell Lefroy succeeded Nicevelle as Government Entomologist.

1905 – Establishment of Imperial Agricultural Research Institute at Pusa, Bihar and Prof. Maxwell Lefroy became he first Imperial Entomologist.

1906 – 'Indian Insect Pests' by Professor Lefroy.

1909 – 'Indian Insect Life' by Professor Lefroy.

1912 – Plant Quarantine Act was enforced.

1914 - Destructive Insects and Pests Act was enforced.

1934 – T.B.Fletcher, published his book "Some South Indian Insects".

1925 – Indian Lac Research Institute started.

1934 - Hem Singh Pruthi who succeeded Fletcher

1938 - Foundation of "Entomological Society of India"

1939 – Locust Warning Organisation was established.

1940 – Dr. T.V. Ramakrishana Ayyar published the book 'Handbook of Economic Entomology for South India'.

1963 – Textbook of Agricultural Entomology by H. S. Pruthi.

1968 – Dr. M.S. Mani "General Entomology"

1969 – Dr. Pradhan's 'Insect Pests of Crops".

Dominance of insects in animal kingdom

Insect constitutes the largest class (Insecta/hexapoda) of the largest phylum (Arthropoda) of the animal kingdom. In the world there are much more types of insect than all other animals. At present more than 10 lakh insects are known and still many more need to be identified. Insects are better adapted and equipped to out number all other animals owing to the following factors:

1. Size: Small size enables insects to live in cracks and crevices and other protected place.

2. Rate of increase: Social insects such as honey bee, ants and wasps have high rate of increase. Queen honey bee can lay 1500- 2000 eggs /day and queen termite can lay 6000 eggs/ day. On an average a female insect can lay 200 eggs during its life span.

3. Adaptibility: The insect can live on land, in soil and in water. They are widely distributed and they can adopt themselves to a wide range of climatic condition.

4. Exoskeleton: It is a strong body covering and affords protection. It prevents entry as well as evaporation of water from the insect body. It gives shape of the body.

5. Food: Insects have a wide range of food habits. Some insects are saprophagous, some are mycophagous, some are blood suckers and some feeds on roots stems, leaves, fruits and flowers.

6. Dispersal: Most of the insects dispersed swiftly by flying, jumping or walking and are able to avoid competition for space and food and slip away from enemies.

7. Behaviour: Some insects are very persistent in behaviour. Such asstick insect, beetles and caterpillars etc. become motionless if disturbed.

8. Means of defence: insects may be provided with different mechanism for protection. Some insects drop down from the plants on the slightest warning other can bite, inject poison, discharge irritating liquid to enemies. Some resemble in size, shape and colour with other.

9. Scattered sense organs: Sense organs in insects are scattered on/in different part sof the body so that if one part of the body is injured, all the senses of the insect may not cease to function. Such as taste receptors are situated on antennae, mouth parts, on ovipositor, on tarsi and distal end of tibia in many lepidopterans, dipterans and honey bees.

10. Complete metamorphosis: This is a specialized phenomenon in which the life history is divided into four parts; egg, larva, pupa and adult. The two feeding stages i.e larva and adult are so different in their structural details , food and habitat requirements that there is no internal competition between the parent and offspring regarding food and shelter.

Classification of Phylum Arthropoda

Insects are six legged arthropods belonging to the Phylum: Arthropoda and Class: Insecta (Hexapoda). Phyla Onychophora and Annelida are closely related to Arthropoda. Arthropoda consists of other animals belonging to subphyla Chelicereta, Crustacea and Atelocereta.

Characters of the Phylum Arthropoda: (Arthro-joint, poda-foot)

i. Segmented body

ii. Segments grouped into 2 or 3 regions known as Tagmosis

iii. Renewable chitinous exoskeleton

iv. Grow by moulting

v. Bilateral symmetry

vi. Body cavity filled with blood-Haemocoel

vii. Tubular alimentary canal with mouth and anus

viii. Dorsal heart with ostia

ix. Dorsal brain with ventral nerve cord

x. Striated muscles

xi. No cilia

xii. Paired segmented appendages

Phylum: Onychophora

i. Antennae segmented

ii. Chitinous exoskeleton

iii. Tracheal system present

iv. Body cavity-haemocoel

v. Body indistinctly segmented, segmentation indicated by presence of legs

Phylum: Annelida

i. Lack of segmented appendages

ii. Lack of chitinous exoskeleton

iii. Lack in tracheal system

iv. Closed circulatory system

v. Nephridia as excretory organs

Eg. Earthworm and leeches

Members of Arthropoda

Subphylum: Crustacea (Crusta - shell)

i. Aquatic and few terrestrial

ii. Body region divided into Cephalothorax and abdomen

iii. Antenna 2 pair - Antennule and Antenna

iv. Appendages biramous

v. Respiration through gill breathing

vi. Circulatory system consists of heart with ostia

Eg. Crabs, prawns and lobsters

Subphylum: Arachnida

i. Terrestrial

ii. Body region divided in to pro, meso and Metasoma

iii. No antenna
iv. Circulatory system consists of heart with ostia

v. Respiration through book lungs (scorpion) and tracheal (spiders)

Eg. Spiders, scorpions, mites and ticks

Subphylum: Atelocereta

i. Uniramous appendages

ii. One pair of antennae

This subphylum includes the following subclasses

Class 1. Diplopoda

i. Terrestrial

ii. Body region divided in to two-head and multisegmented trunk

iii. One pair of antennae

iv. Mouth parts mandibulate

v. Tracheal respiration

vi. Elongated worm like with more than 30 pairs of legs

vii. Most of the segments bear two pair of legs

Class 2. Chilopoda

i. Terrestrial

ii. Elongated flattened body with more than 15 pairs of legs

iii. Each body segment bear single pair of legs

iv. Tracheal respiration

v. Body region divided in to two-head and multisegmented trunk

Class 3. Pauropoda

i. Antennae bear 3 apical branches

ii. Nine pairs of legs

iii. Genital opening anterior end of the body

Class 4. Symphyla

i. Antennae slender and many segmented

ii. Genital opening anterior end of the body

iii.10-12 pairs of legs

Class 5. Hexapoda

i. Body bilateral symmetry

ii. Body is divided into three regions head, thorax and abdomen

iii. In head a pair of antenna and a pair of compound eyes are usually present.

iv. Thorax with three distinct segments called prothorax, mesothorax and metathorax

iv. Thorax is the centre of locomotion with, 3 pairs of five jointed legs and two pairs of wings.

v. Abdomen 11 segmented plus a telson

vi. Malphigian tubule as excretory organ

vii. Tracheal system of respiration well developed.

viii. Brain is divided into protocerebrum, deutocerebrum and tritocerebrum.

ix. Circulatory system open type consists of heart with ostia

INSECT CUTICLE

Integument or body wall of an insect consists of inner cellular layer (Epidermis), an outer non cellular part (Cuticle) and basement membrane.

Cuticle: It is an outer non cellular layer comprising of three sub layers.

i.Endocuticle: Compared to others it is the inner and thickest layer. This layer is made up of chitin and arthropodin. This layer is colourless, soft and flexible.

ii.Exocuticle: Outer layer, much thicker with the composition of chitin and sclerotin. This layer is dark in colour and rigid.

iii.Epicuticle: Outer most layers which is very thin. Pore canals present in the exocuticle helps in the deposition of epiculticle. This layer is differentiated into the following layers.

a.Inner epicuticle: It contains wax filaments

b.Outer epicuticle: It makes the contact with cuticulin

c.Cuticulin : Non chitinous polymerised lipoprotein layer.

d.Wax layer: It contains closely packed wax molecules which prevents desiccation.

e.Cement layer: Outer most layer formed by lipid and tanned protein. It protects wax layer.

Epidermis: It is an inner unicellular layer resting on basement membrane with the following function.

i. Cuticle secretion

ii. Digestion and absorption of old cuticle

iii. Wound repairing

Basement Membrane: It is generally 0.5 μ or less in thickness and appears as a continuous, amorphous granular layer. It is non cellular is structure. It apparently consist of mucopolysaccharide

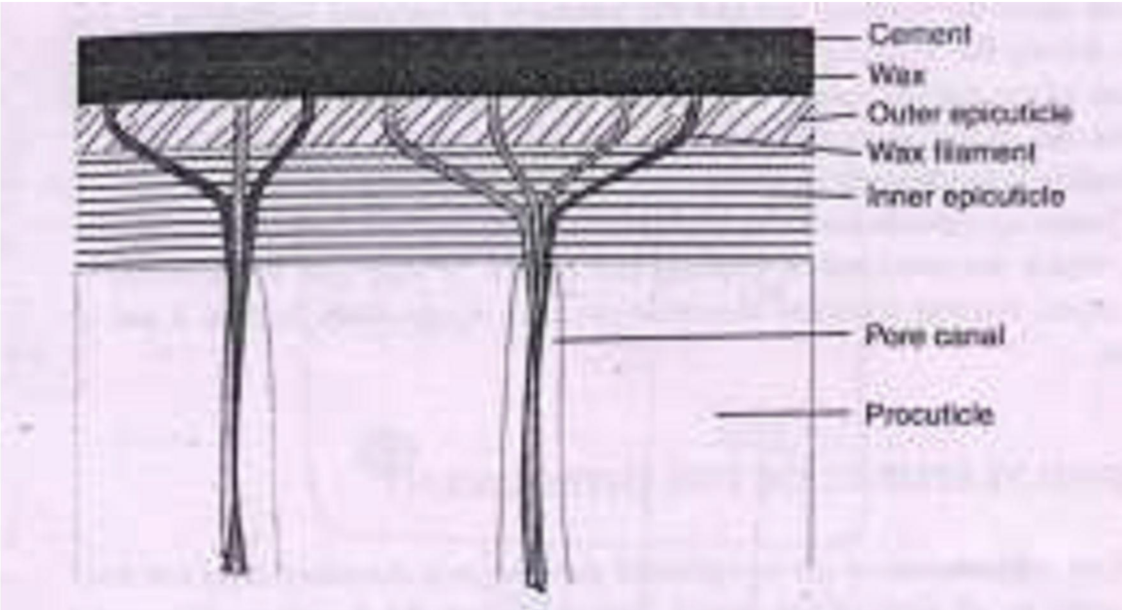
Cuticular outgrowth: The integumentary processes can be classified as cellular and noncellular. In the cellular processes, some are unicellular, others are multicellular.

Non-cellular: Non-cellular appendages have no epidermal association, but rigidly attached. e.g. minute hairs and thorns.

Cellular: Cellular appendages have eipdermal association.

Unicellular processes referred as setae. They are commonly hair like, but may be flattened in to scale.

Multicellular: e.g. Spur - movable structure and Spine- immovable structure



Composition of cuticle

MOULTING

Periodical process of shedding the cuticle accompanied by the formation of new cuticle is known as moulting or ecdysis. The cuticular parts discarded during moulting is known as exuvia. It occurs in immature stages before attaining the adulthood. The time interval between the two subsequent moulting is known as stadium and the form assumed by the insect in any stadium is called as instar.

Steps in moulting :

1. Behavioural changes
2. Changes in epidermis
3. Apolysis

4. Formation of subcuticular space
5. Secretion of moulting gel
6. New epicuticle formation
7. Procuticle formation
8. Activation of moulting gel
9. Rupturing of old cuticle
10. Removal of old cuticle
11. Formation of exocuticle – through addition of protein and tanning by phenolic substance.
12. Formation of endocuticle - through addition of protein and chitin. This layer increase in thickness.

Control of moulting – controlled byendocrine glands e.g. Prothoracic gland which secrete moulting hormone.

BODY SEGMENTATION

Sclerites

The integument remain flexible in all parts as in larvae but usually hardened or sclerotised in definite areas forming sclerites.

Segmentation

The whole body of insect is divided into three parts viz; head, thorax and abdomen. Each body segment or somite or metamere is made up of four exposed faces or views. A major segmental plate of the dorsal called Tergum (Notum on thorax) ventral- Sternum and lateral plate- Pleuron. Subdivision of tergum, the sclerites are called as Tergites, that of sternum sclerites - sternites and pleural sclerites- Pleurites.The typical number of segments in insect body is twenty.

Head – made up of six segments fused together to form the head.

Thorax – Three segments are fused together. First segment is prothorax, second is mesothorax and third is metathorax. One pair of leg arises from each segmentand further each of meso and metathorax bear a pair of wings and called pterothorax.

Abdomen – The remaining eleven segments are found in abdomen. Only organs of reproduction are borne on it. Cerci are present on 10 th segment.Anal styles are absent in female.

INSECT HEAD AND ITS STRUCTURE

The insect head is a strongly sclerotized capsule joined to the thorax by a flexible membranous neck. It bears the mouthparts comprising the labrum, mandubles, maxillae and labium, and also the serve organs, the antennae, compound eyes and ocelli.

Areas of Head

- The surface of the head is divided into regions (sclerites) by a pattern of shallow grooves (sutures).
- The uppermost sclerite (dorsal surface) of the head capsule is known as the vertex. A coronal suture usually runs along the midline of the vertex and splits into two frontal sutures as it extends downward across the front of the head capsule.
- The triangular sclerite that lies between these frontal sutures is called the frons.
- The epistomal suture is a deep groove that separates the base of the frons from the clypeus, a rectangular sclerite on the lower front margin of the head capsule.
- The genae are lateral sclerites that lie behind the frontal sutures on each side of the head.
- Below each gena there may be another sclerite (the subgena), separated from the gena by a subgenal suture.
- A pair of compound eyes, sockets for two antennae, and one or more ocelli (simple eyes) also may be found on the front, top, or sides of an insect's head.
- The insect's neck is known as the cervix.
- Posterior line of inflection on the head capsule- postoccipital suture
- Area behind post-occipital suture- postoccipital
- Area on side of the head anterior to pos- occiput
- Weak lines which help in moulting- Ecdysial cleavage
- Sulcus surrounding compound eye- Circum ocular sulcus
- Sulcus surrounding antenna- Antennal sulcus
- Sulcus extending below compound eye- Subocular sulcus

Types of Insects head

Hypognathous: Primitive, phytophagous, the long axis of the head is vertical i.e. at right angle to the long axis of the body. The mouthparts point downwards e.g. grasshopper, cockroach etc.

Prognathous: The long axis of the head is horizontal and in line with the long axis of the insects body. The mouthparts are directed forwards e.g. Coleopteran grub, Stick insect, soldier caste of termites etc.

Opisthognathous: The head is reflexed ventrally so that the mouth parts are directed backwards between the coxae of the front legs e.g. Red cotton bug

Tentorium: In all insects, the rigidity of the head is increased by deep cuticular invaginations known as apodemes, which meet internally to form a brace for the head and for the attachment of muscles. The structures formed by these invaginations is called the tentorium. Two anterior arms arise from the anterior tentorial pits. The posterior arms arise from the pits at the ventral ends of the postoccipital suture and they unite to form the terrtorial bridge surviving across the head from one side to another.

Structure of Thorax – Three segments are fused together. First segment is prothorax, second is mesothorax and third is metathorax. One pair of leg arises from each segment i.e. foreleg, midleg and hindleg. Each of meso and meta thorax bears a pair of wings i.e. forewing and hindwing and wing bearing thorax are called pterothorax.

Thoracic nota: Dorsal body plate of each thoracic segments are called as pronotum, mesonotum and metanotum respectively.

Pronotum: This sclerite is undivided and saddle shaped in grasshopper and shield like in cockroach.

Thoracic sterna: Ventral body plate of each thoracic segment and made up of a segmental plate called eusternum and an intersternitecalled spinasternum.

Thoracic pleura: Lateral body plates. Pleural plate is divided into anterior episternum and posterior epimeron by pleural suture. Pterethoracic pleuron provides space for articulation of wings and legs.

Thoracic appendages are three pairs of legs and two pairs of wings. Two pairs of spiracles are also present in the mesopleuron and metapleuron..

Structure of Abdomen and its appendages

Body segmentation is more evident in the abdomen of insects. The basic number of abdominal segments in an insect is eleven, plus a telson, which bears the annus. The abdominal segments are called uromeres. On the eighth and ninth segments of the female and ninth segment of the male, the appendages are modified as external organ of reproduction or genitalia. The segments are known as genital segments. Usually eight pairs of small spiracles are present on the first eight abdominal segments. The triangular dorsal plate of eleventh segment is called epiproct and paired lateral plates are called paraprocts. A pair of creci is present between the epiproct and paraprocts.

Appendages

a. Pre-genital appendages in wingless insect

Styli

A varying tube of pair tube like outgrowth are found on the ventral side of the abdomen of silverfish

b. Abdominal appendages in larvae

Tracheal gills

Gills are lateral outgrowths of body wall which are richly supplied with tracheae to obtain oxygen from water. Seven pairs of filamentous gills are present in the first seven abdominal segments of naiads of mayfly. Leaf like gills (lamellate) is found at the end of adbomen of naiad of damselfly.

Anal papillae

A group of four papillae surrounds the anus in mosquito larvae, which concerned with salt regulation.

Dolichasters

These structures are found on the abdomen of antlion grub. Each dolichaster is a segmental protuberance fringed with setae.

Proloegs

These are present in the larvae of moth, butterfly and sawfly. Two to five pairs are normally present and are unsegmented, thick and fleshy. The tip of the proleg is called planta upon

which are borne heavily sclerotised hooks called crochets. They aid in crawling and clinging to surface.

c. Abdominal appendages in winged adults

Cornicles

Aphids have a pair of short tubes known as cornicles or siphonculi projecting from dorsum of fifth or sixth abdominal segment. They permit the escape of waxy fluid which perhaps serves for protection against predators.

Cerci

They are the most conspicuous appendages associated normally with the eleventh abdominal segment. They are sensory in function. They exhibit wide diversity and form.

Long and many segmented e.g. Mayfly
Long and unsegmented e.g. Cricket
Short and many segmented e.g. Cockroach
Short and unsegmented e.g. Grasshopper
Sclerotised and forceps like e.g. Earwig. Cerci are useful in defense, prey capture, unfolding wings and courtship.
Asymmetrical cerci e.g. Male embiid. Left cercus is longer than right and functions as clasping organ during copulation.

Median caudal filament

In mayfly and silverfish, (Wingless insect) the epiproct is elongated into a cercus like median caudal filament.

Pygostyles

A pair of unsegmented cerci like structures is found in the last abdominal segment of scoliid wasp.

Anal styli

A pair of short unsegmented structures is found at the end of the abdomen of male cockroach. They are useful to hold the female during copulation.

Ovipositor

The egg laying organ found in female insect is called ovipositor. It is suited to lay eggs in precise microhabitats. It exhibits wide diversity and form.

Short and horny e.g. Short horned grasshopper

Long and sword like e.g. Katydid, long horned grasshopper

Needle like e.g. Cricket

Structure and modification of antennae

All insects possess a pair of antennae, but they may be greatly reduced, especially in larval forms. But protura do not have antenna.

Structure

The antenna consists of a basal scape, a pedicel and a flagellum. The scape is inserted into a membraneous region of the head wall and joined on a single marginal point called antennifer, so it is freely moves in all directions. Flagellum is divided into a number of similar annuli joined to each other by membranes so that the entire flagellum is flexible. The antennae of the insects are moved by levator and depressor muscles arising on the anterior tentorial arms and inserted into the scape, and by the flexor and extensor muscles arising in the scape and inserted into the pedicel.

Functions of antennae

1. Olfactory reception
2. Johnston's organ helps in the regulation of oil speed in flying insects
3. Perception of near field sound-male mosquito, female Drosophila, worker honey bee
4. Hydrofuge hairs helps in the formulation of air funnel-Adult water beetle Hydrophilus
5. Assist the mandible in masticating the play - newly hatched grubs of Hydrophilus
6. To clasp the female during mating - Fleas and Collembola.

Modifications/types of Antenna

1. Setaceous: Bristle like. Very small sized, segment size decreases from base to apex and ends with a bristle or become pointed. e.g. Leaf hopper, Dragonfly, Damselfly

2. Filiform: Thread like segments are many and cylindrical e.g.Orthopterans,Dictyopterans, moths

3. Moniliform: Beaded segments are either globular or spherical with prominent constriction in between e.g. Termites, thrips

4. Clavate: Clubbed antenna enlarges gradually towards the tip e.g Butterfly

5. Capitate: Knobbed terminal antennal segments enlarged suddenly, e.g.. Blister beetle, red rust flour beetle

6. Hooked: Knobbed end of the antenna is hooked e.g. Skippers and sphingids

7. Bipectinate: Double comb like antennal segments processes long slender lateral process on both the sides e.g. Silkworm moth

8. Unipectinate: Comb like antennal segments with long slender processes on one side e.g. Sawfly

9. Plumose: Feathery segments with dense and long whorls of hails e.g. Male mosquito

10. Pilose: Hairy antenna is less feathery with few hairs at the junction of flagellomeres. e.g. Female mosquito

11. Aristate: Antenna with three segments and the terminal segment bears a dorsal bristle called arista e.g. House fly

12. Stylate: Antenna three segmented and the terminal segment ends with a style like process e.g. Robber fly, Horse fly

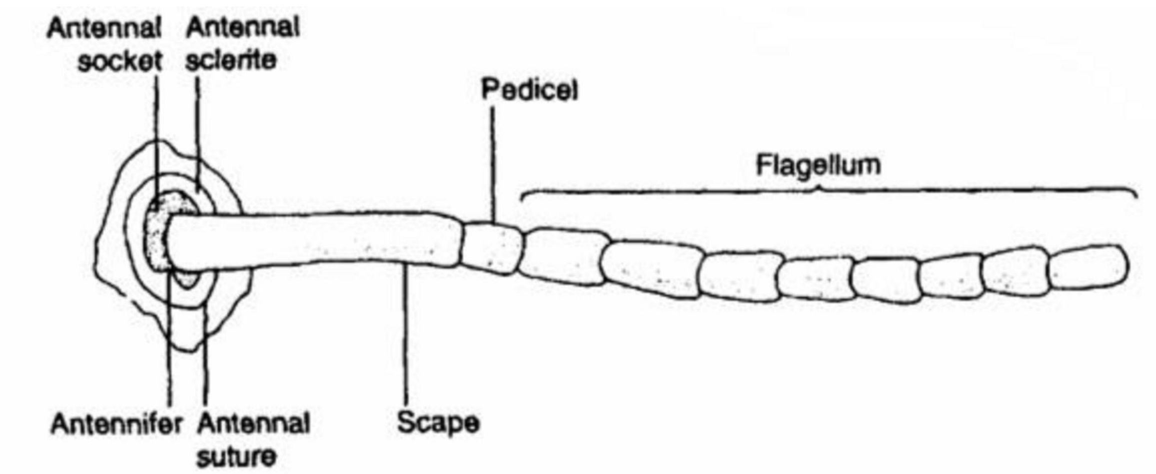
13. Serrate: Saw like Segments have short triangular projection on one side. e.g. Long horned beetles, pulse beetle, jewel beetles, click beetles

14. Lamellate: Plate like Small sized, antennal tip is laterally expanded to flat plates e.g. Rhinoerous beetle, ground beetles

15. Geniculate: Elbowed basal scape is relatively long. Remaining segments are small and are arranged at an angle to the scape forming an elbow like joint e.g. Ant, weevil, honey bee

16. Caterpillar type: Very small, with reduced antennal segments e.g. Lepidoptera larva

17. Flabellate: Very small, third and subsequent segments with side processes giving a fan like arrangement e.g. Strepsipterans (or) Stylopids



Structure of insect antennae

Types of insect mouthparts

Insects (Class Insecta) exhibit a range of mouthparts, adapted to particular modes of feeding. The earliest insects had chewing mouthparts. There are mainly of two types *viz*. mandibulate (feeding mainly solid food) and haustellate (feeding mainly on liquid food).

1. Chewing and Biting type (E.g. Grasshopper & Cockroach)

a. Labrum: The labrum is the anterior-most mouthpart. It forms flap like, bilobed suspended from the clypeus and protects the more delicate mouthparts behind it. It is movable. It essentially forms the roof of the mouth and is useful for pulling food into the mouth. It moves longitudinally (i.e. an up and down motion) and is hinged to the clypeus.

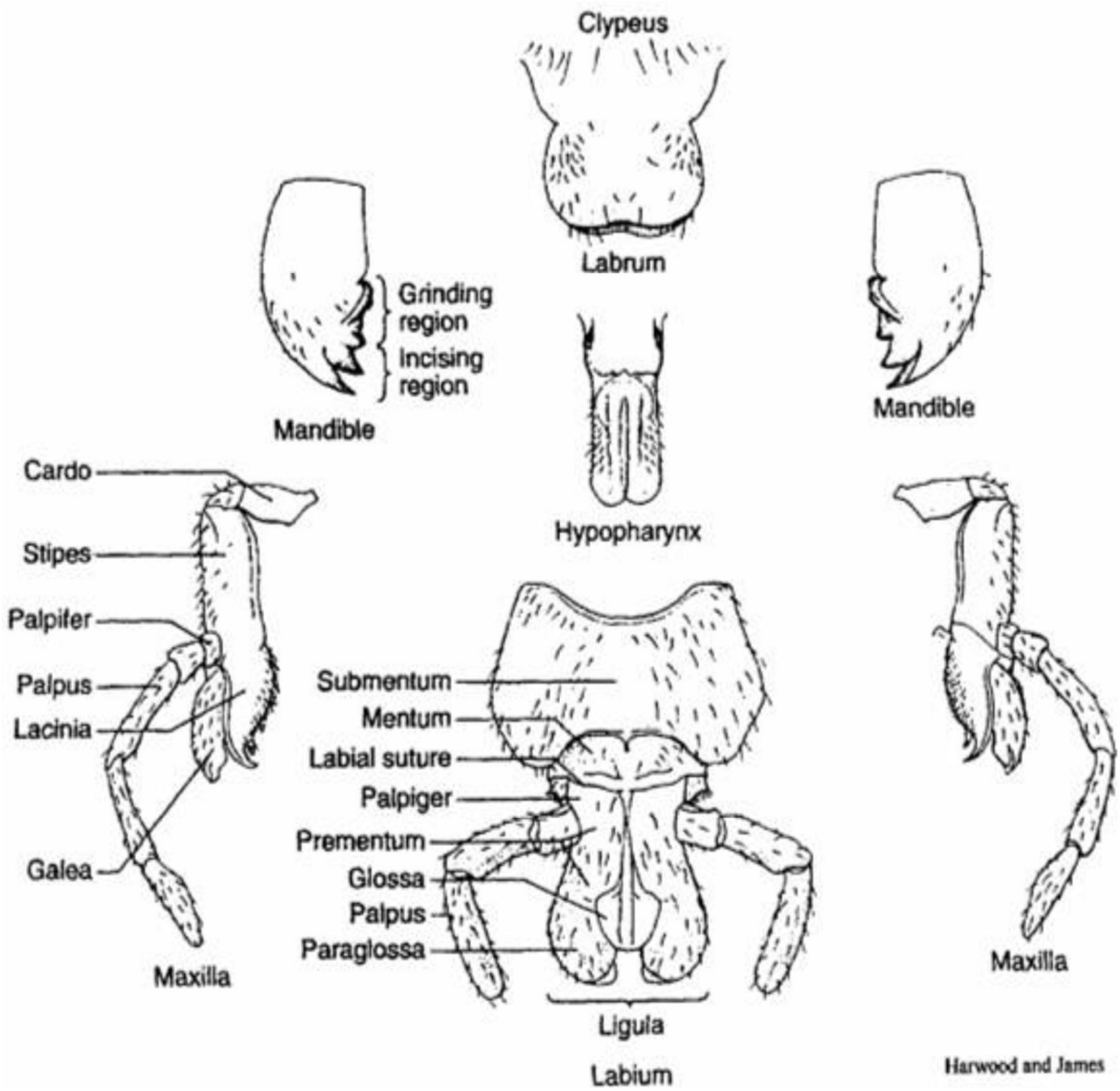
b. Labrum-epipharynx: The inner surface of the labrum is referred as epipharynx. It is membranous and continuous with dorsal wall of pharynx. The epipharynx is covered with chemoreceptors and mechanoreceptors used in food selection.

c. Mandibles: Chewing insects have two mandibles, one on each side of the head. The mandibles are positioned between the labrum and maxillae. They are typically the largest mouthparts of chewing insects, being used to masticate (cut, tear, crush, chew) food items. They are tooth on their inner border. There are two types of teeth. Distal are sharply pointed and called incisor or cutting teeth and proximal teeth are called molar or grinding teeth.

d. Maxillae: They form the second pair of jaws and are located behind the mandibles. Maxillae are used for handling food and moves laterally much like the mandibles. The main body of the maxilla is composed of the proximally located cardo and the distally located stipes. Distally on the stipes are two lobes, an outer galea and an inner lacinia which is toothed. Maxillae direct the food in to the mouth. They hold the food in place when the mandible is in action. They act as auxillary jaws and assist mastication of food.

e. Hypopharynx: It is a tongue like organ located centrally in the preoral cavity. The duct of salivary gland opens through it.

f. Labium: The labium is the posterior-most mouthpart and is derived from the fusion of two maxillae-like appendages. It forms the protective “lower lip” to the mouth. The main body of the labium consists of three plate-like segments (submentum, mentum and prementum). The most distally located segment bears four lobes, two inner glossae and two outer paraglossae collectively known as ligula. A pair of palps also arise laterally. These labial palps typically act as sensory organs similar to the maxillary palps.



Chewing and biting type of mouthparts

2. Piercing and sucking type or hemipterous bug type (E.g. Plant bug)

Labium projected down words like a beak form the anterior part of the head. The beak is four segmented and ground throughout its entire length. At the base of the labium, there is a triangular flap like structure called labium. Labium functions as a protective covering for the four stylets found within the groove. Both mandible and maxillae modified into long slender hair like structure called stylets. They lie close together and suited for piercing and sucking. The tips of the stylets may have minute teeth for piercing the plant tissue. The inner maxillary stylets are doubly grooved on their faces. When these are closely opposed they form two cannals viz, food canal and salivary canal through which plant sap and salivary are conducted, respectively. Saliva contains enzyme or toxin that can distort plant cell wall to permit the stylets to penetrate down and reach the phloem for sucking the sap. Salivary enzymes perform extra oral digestion within the plant cell.

3. Piercing and sucking type or dipterous mosquito type (E.g. Female mosquito)

Mouthparts of female mosquito consist of an elongate labium which is grooved forming a gutter which encloses six stylets. The stylets are composed of labrum - epipharynx (enclosing the food canal), the hyphophrynx (containing the salivary canal), two maxillae and two mandibles. Both the ends of maxillary stylets and mandibular stylets are saw like and suited piercing flesh. The stylets are inserted into host's skin by a strong downward and forward thrust of body. Both mandibles and maxillae are reduced in male and they feed on plant nectar and juices of decaying fruits. Female pierces the skin of human beings into which it injects saliva containing an anticoagulant (to keep the blood flowing without clotting) and an anesthetic (to keep the victim unaware of the bite) and sucks up the blood. Labium does not pierce but folds up or back as stylets pierce. Maxillary palpi are present.

4. Chewing and lapping type (E.g. Honey bee)

Labrum and mandibles are as in biting and chewing type of mouthparts. But mandibles are blunt and not toothed. They are useful to crush and shape wax for comb building; ingest pollen grains and other manipulative functions. Maxillolabial structures are modified to form the lapping tongue. The tongue unit consists of two galea of maxillae, two labial palpi and elongated flexible hairy glossa of labium. The glossa terminates into a small circular spoon shaped lobe called spoon or bouton or flabellum which is useful to lick the nectar.

5. Rasping and sucking type (E.g. Thrips)

Mouth cone consists of labrum, labium and maxillae. There are three stylets derived from two maxillae and left mandible. Right mandible is absent. Stylets are useful to lacerate the plant tissue and the oozing sap is sucked up by the mouth cone. Both maxillary palpi and labial palpi are present.

6. Sponging type (House fly)

The proboscis is fleshy, elbowed, retractile and projects downwards from head. The proboscis can be differentiated into basal rostrum and distal haustellum. The proboscis consists of labium which is grooved on its anterior surface. Within this groove lie the labrum-epiphraynx (enclosing the food canal) and slender hypopharynx (containing the salivary canal). Mandibles are absent. Maxillae are represented by single segmented maxillary palpi. The end of the proboscis is enlarged, sponge like and two lobed which acts as suction pads. They are called oral discs or labella. The surfaces of labella are transvered by capillary canals called pseudotracheae which collect the liquid food and convey it to the canal. Labella function as sponging organs and are capable of taking exposed fluids.

7. Mandibulosuctorial type (E.g. Grub of antlion)

Mandibles are elongate sickle shaped and grooved on the inner surface. Each maxilla is elongated and fits against the mandibular groove to from a closed food canal. The body of the insect victim is pierced by the opposing mandibles and fluids are extracted.

8. Siphoning type (E.g. Moths and butterflies)

Mouth parts consist of elongate sucking tube or proboscis. It is formed by two greatly elongated galeae of maxillae which are zippered together by interlocking spines and hooks.

Galeae are grooved on their inner surface and when they are fitting together closely they form a suctorial food canal through which the nectar is sucked up. The proboscis is coiled up like watch spring and kept beneath the head when it is not in use. By pumping of blood into galeae, the proboscis is extended. The other mouth parts are reduced or absent except the labial palpi and smaller maxillary palpi.

Structure of insect legs and their modification

The fore-legs are located on the prothorax, the mid-legs on the mesothorax, and the hind legs on the metathorax. Each leg has six major components, listed here from proximal to distal: coxa (plural coxae), trochanter, femur (plural femora), tibia (plural tibiae), tarsus (plural tarsi), pretarsus.

Coxa

The coxa is the proximal segment and functional base of the leg. It articulates with the pleuron and associated sclerites of its thoracic segment. It is generally freely movable.

Trochanter

The trochanter articulates with the coxa but usually is attached rigidly to the femur. In some insects its appearance may be confusing; for example it has two subsegments in the Odonata. The apparent second trochanter is in fact a part of femur, which is called trochantellus.

Femur

It is the largest and stoutest part of the leg and it is closely attached to the trochanter.

Tibia

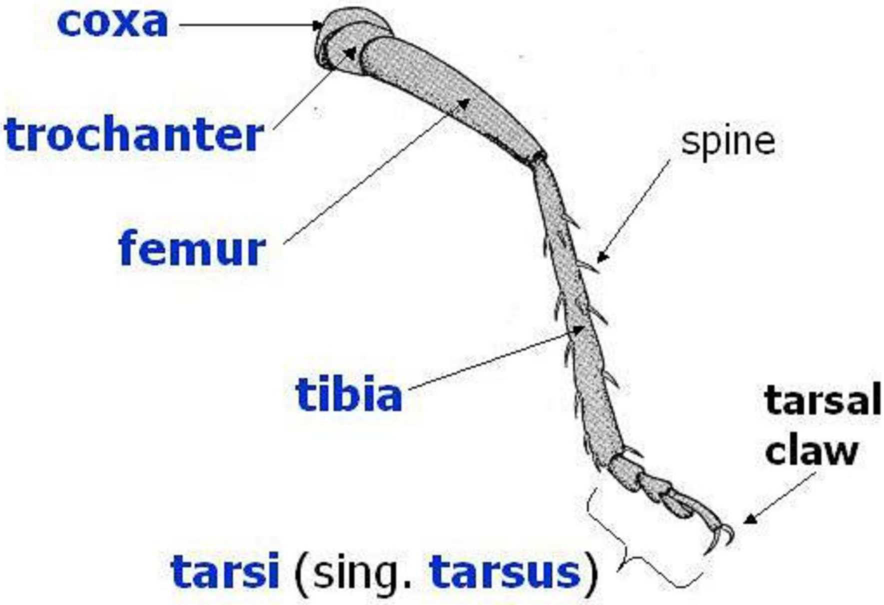
It is usually long and provided with downward projected spines which aid in climbing and footing. Tibia of many insect is armed with largely movable spur near the apex.

Tarsus

It is further subdivided. The subsegment of the tarsus is called tarsomere. The number of tarsomere varies from one to five. The basal tarsal segment is longer than the other and is named as basitarsus.

Pretarsus

Beyond the tarsus, there are several structures collectively known as pretarsus. Tarsus terminates in a pair of strongly curved claws with one or two pair pads or cushion at their base between them. A medium pad between claws known as arolium and a pair of pads at their base is known as pulvilli. Leg pads are useful while walking on smooth surface and claws give needed grip while walking on rough surface. When one structure is used, the other is bent upwards.



Parts of insect leg

Modification of insect legs:

Ambulatorial (Ambulate - To walk; Walking leg) e.g. fore leg and middle leg of grasshopper. Femur and tibia are long. Legs are suited for walking.

Cursorial (Cursorial = Adapted for running: Running leg) e.g. All the three pairs of legs of cockroach.

Legs are suited for running. Femur is not swollen. At top speed, a cockroach moves 4.6 Km/hour.

Saltatorial (Salatorial = Leaping; Jumping Leg) e.g. hind leg of grasshopper.

Trochanter is fused with femur. Hind femur is enlarged to accommodate powerful extensor muscles of tibia which are used for leaping. Tibia is long and slender. Two rows of spines are present along the ventrolateral edges. It is heavily sclerotised and rigid, since the force of leaping is exerted against it.

Scansorial (Scansorial = Climbing; climbing or clinging leg) e.g. all the three pairs of legs of head louse.

Legs are modified for clinging to the hairs of its host. Tibia is stout and at one side bears a thumb like process. The tarsus is single segmented. There is a single large claw that usually fits against a thumb like process which forms an efficient mechanism for hanging to the hairs of host. Tarsus and pretarsus work against the thumb in much the same way as the human forefinger works against the thumb in grasping an object.

Fossorial (Fossorial = Digging; Burrowing leg) e.g. fore leg of mole cricket.

Forlegs of mole cricket are used as cutting and shoveling implements. Femur is stout. Tibia is short and stout and bears distally two or three strongly pointed teeth. The first two segments of tarsus are also produced into strong teeth. The teeth of basitarsus work against one of the tibial tines to function as shears in cutting fine rootlets. Tympanum is present in fore tibia.

Raptorial (Raptorial = Predatory; Grasping leg) e.g. fore leg of preying mantis.

Forelegs are prehensile and suited for capturing the prey. They are of no use in locomotion. Coxa is long and mobile. The elongated coxae given an extended reach to capture the prey. The femur is large and grooved along the ventral surface with spines on the two opposing surfaces of femur. The spiny tibia fits into the femoral groove when it snaps down over the prey. Tarsus consists of five tarsomeres.

Natatorial (Natatorial = Pertaining to swimming; Swimming leg) e.g. hind legs of water bug and water beetle.

Hind legs are highly specialized for swimming. Femur, tibia and the first four tarsomeres are all broad and flattened. Their edges are provided with flattened setae which serve as oars.

Sticking leg: e.g. all the three pairs of legs of house fly.

Pretarsus consists of a pair of lateral adhesive pads under the claws called pulvilli. Arolium is absent. But a median spine like structure empodium is present. The pulvilli are covered with dense mats of tiny glandular hairs called tenant hairs. Secretions of these glandular hairs are helpful in clinging to smooth surface and to walk upside down on the celling.

Basket like leg: e.g. legs of dragonfly and damselfly.

Legs are situated just behind the head and are anterior in position. Legs are spiny and closely placed, which are useful in seizing the prey during flight. Captured insects are kept in the leg basket. Legs are not useful in locomotion.

Clasping leg: e.g. foreleg of male water beetle.

The leg is modified for reproduction purposes. Coxa and trochanter are normal and smaller, while femur is thick. The tibia is slender and directed towards femur from its inner side. The tarsus is one segmented and attached. During reproduction this adaptation enables the male to hold the female easily.

Foragial leg or pollen collecting leg: (Forage = To collect food material) e.g. legs of honey bees

i. Foreleg: The foreleg has three important structures.

a. Eye brush : Hairs on tibia constitute eye brush which is useful to clean the compound eyes.

b. Antenna cleaner or strigillis : It consists of two structures viz., vellum and antenna comb. Velum is a movable clasp present at distal end of tibia. Antenna comb is a semicircular notch lined with small spines. Antenna cleaner is useful to clean the antenna.

c. Pollen brush: Bristles on basitarsus form pollen brush which is useful to collect pollen from the head and mouthparts.

ii.Middle leg: It has two important structures.

a. Pollen brush: Stiff hairs on basitarsus form pollen brush which is useful to collect pollen from middle part of their body.

b. Tibial spar: At the distal end of the tibia, a movable spur is present which is useful to loosen the pellets of pollen from the pollen basket of hind legs and to clean wings and spiracles.

iii. Hind leg: It has three important structures viz., Pollen basket, Pollen packer and Pollen comb.

a. Pollen basket: It is called corbicula. The outer surface of the hind tibia contains a shallow cavity. The edges of the cavity are fringed with long hairs. The pollen basket enables the bee to carry a larger load of pollen and propolis from the field to the hive.

b. Pollen packer: It is called pollen press. It consists of pecten and auricle. Pecten is a row of stout bristles at the distal end of tibia. Auricle is a small plate fringed with hairs at the basal end of basitarsus. Pollen packer is useful to load pollen in corbicula.

c. Pollen comb: About ten rows of stiff spines are present on the inner side of hind basitarsus. The pollen comb is used to collect pollen from middle legs and from posterior part of the body.

Prolegs or False legs or pseudolegs: e.g. abdominal legs of caterpillar.

There are two to five pairs of abdominal legs termed prolegs in caterpillar. Prolegs are thick, fleshy and not segmented. They are shed with last larval moult. One pair of prolegs on the last abdominal segment is called anal prolegs or claspers. The tip of proleg is called planta upon which are borne hooks or claws known as crochets which are useful in crawling or clinging to surface.

WING, WING VENATION AND MODIFICATIONS

Among the invertebrate animals, only insects possess wings. Wings are present in adult stage. Number of wings varies from two pairs to none. Certain primitive insects like silver fish and spring tail have no wings (apterous). Ecto parasites like head louse, poultry louse and flea are secondarily wingless. Wings are deciduous in ants and termites. There is only one pair of wings in the true flies. Normally two pairs of wings are present in insects and they are borne on pterothoracic segments *viz*., mesothorax and metathorax. Wings are moved by thoracic flight muscles attached to their bases.

Wing is flattened double layered expansion of body wall with a dorsal and ventral lamina having the same structure as the integument. Both dorsal and ventral laminae grow, meet and fuse except along certain lines. It is nourished by blood circulating through veins. Later the

walls of these channels become thickened to form veins. The arrangement of veins on the wings is called venation which is extensively used in insect classification. The principal longitudinal veins arranged in order form the anterior margin are costa (C), sub costa (Sc), radius (R), median (M), cubitus (Cu) and anal veins (A). Small veins often found inter connecting the longitudinal veins are called cross veins. In insects like dragon fly and damselfly, there is an opaque spot near the coastal margin of the wing called pterostigma.

Margins and Angles

The wing is triangular in shape and has therefore three sides and three angles. The anterior margin strengthened by the costa is called costal margin and the lateral margin is called apical margin and the posterior margin is called anal margin. The angle by which the wing is attached to the thorax is called humeral angle. The angle between the costal and apical margins is called apical angle. The angle between apical and anal margins is called anal angle.

Wing Regions

The anterior area of the wing supported by veins is usually called remigium. The flexible posterior area is termed vannus. The two regions are separated by vannal fold. The proximal part of vannus is called jugum, when well developed is separated by a jugal fold. The area containing wing articulation sclerites, pteralia is called axilla.

Insects have evolved many variations of the wings, and an individual insect may possess more than one type of wing. Wing venation is commonly used as taxonomic character, especially at the family and species level.

In most living insects (the Neoptera), there are three axillary sclerites that articulate with various parts of the wing. In the Neoptera, a muscle on the third axillary causes it to pivot about the posterior notal wing process and thereby to fold the wing over the back of the insect. (In some groups of Neoptera, such as butterflies, the ability to fold the wings over the back has been lost.) Two orders of winged insects, the Ephemeroptera and Odonata, have not evolved this wing-flexing mechanism, and their axillary sclerites are arranged in a pattern different from that of the Neoptera; these two orders (together with a number of extinct orders) form the Paleoptera.

Modification

1. Tegmina

Tegmina (singular tegmen) are the leathery forewings of insects in the orders Orthoptera, Dictyoptera and Mantodea. The tegmina helps to protect delicate hind wings. They are not used for flight. E.g. grasshoppers, crickets and katydids (order Orthoptera), cockroaches (suborder Blattaria), Mantids (order Mantodea).

2. Elytra

The wing is heavily sclerotised. Wing venation is lost. It is tough and protective in function. It protects hind wings and abdomen. It is not used during flight, but during flight they kept at an angle allowing free movement of hind wings. e.g. fore wings of beetles and weevils.

3. Hemelytra

The basal half of the wing is thick and leathery and distal half is membranous. They are not involved in flight and are protective in function. e.g. fore wing of heteropteran bugs.

4. Halteres

In true flies the hind wings are modified into small knobbed vibrating organs called haltere. Each haltere is a slender rod clubbed at the free end (capitellum) and enlarged at the base (scabellum). They act as balancing organs and provide the needed stability during flight. e.g. true flies, mosquito, male scale insect.

5. Fringed wings

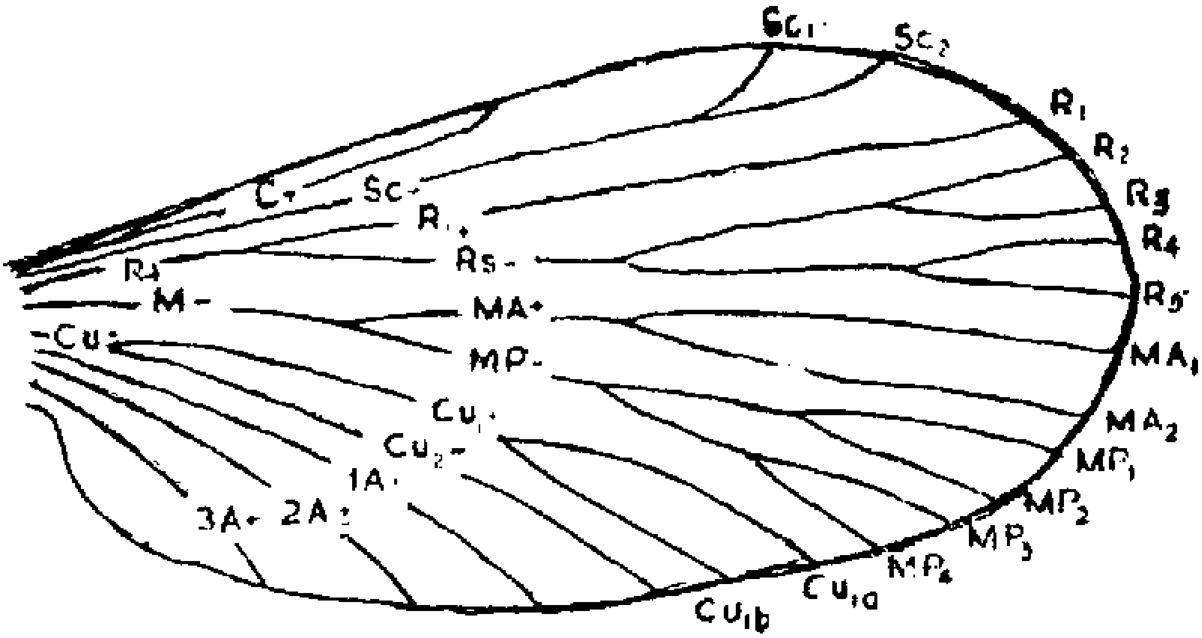
Fringed wings are usually reduced in size. Wing margins are fringed with long setae. These insects literally swim through the air. e.g. thrips.

6. Scaly wings

Wings of these insects are covered with small coloured scales. Scales are unicellular flattened outgrowth of body wall, inclined to the wing surface and overlap each other to form a complete covering. Scales are responsible for colour and are important in smoothing the air flow over wings and body. E.g. butterfly and moth

7. Membranous wings

Transparent wings are called membranous wings. They are thin and supported by a system of tubular veins. In many insects either forewings or hind wings or both fore wings and hind wings are membranous. They are useful in flight. E.g. fore wing of true flies, hind wings of grasshopper, cockroaches, etc



Wing veins and venation

WING COUPLING MECHANISM

1. Hamulate: A row of small hooks is present on the coastal margin of the hind wing which is known as hamuli. These engage the folded posterior edge of fore wing. e.g. bees.

2. Amplexiform: It is the simplest form of wing coupling. A linking structure is absent. Coupling is achieved by broad overlapping of adjacent margins. e.g. butterflies.

3. Frenate: There are two sub types. e.g. Fruit sucking moth.

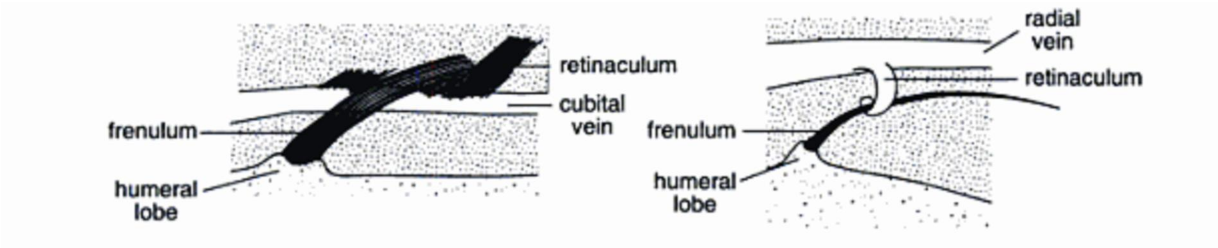
i. Male frenate: Hindwing bears near the base of the coastal margin a stout bristle called frenulum which is normally held by a curved process, retinaculum arising from the subcostal vein found on the surface of the forewing.

ii. Female frenate: Hindwing bears near the base of the costal margin a group of stout bristle (frenulum) which lies beneath extended forewing and engages there in a retinaculum formed by a patch of hairs near cubitus.

4. Mecopteran types of wing coupling: Here the jugal lobes lie on top of the hind wings while the humeral bristles form the frenulum, which press against the underside of the fore wing. e.g. mecoptera

5. Jugate type: The jugal area is produced into a lobe like fibula or elongates jugum, which lies on top of the hind wing during flights. e.g. trichoptera

Frenate coupling - female **Frenate coupling - male**



METAMORPHOSIS AND DIAPAUSE IN INSECTS

Metamorphosis in Insects

It is the change in growth and development an insect undergoes during its life cycle from birth to maturity. There are four basic types of metamorphosis in insects.

Ametabola (Nometamorphosis): life stages: egg-young one-adult

It is the most primitive type of metamorphosis. The hatched insect resembles in adult in all aspects except for the size. Moulting continuous throughout the life. e.g. silverfish

Hemimetabola (Incomplete metamorphosis): life stages: egg-naiad-adult

The young ones are aqatic called naiads. The appearance is different form adults. They breathe by means of tracheal gills. Their lower lip is called mask, which is hinged and provided with hooks for capturing prey. Habit, habitat and food of the adult and naiads are different. After final moult, insect will have fully developed wings suited for aerial life. e.g. dragonfly, damselfly and mayfly.

Paurometabola (Gradual metamorphosis): life stages: egg-nymph-adult

The young ones are called nymph. They are terrestrial and resemble the adults in general body form. Their compound eyes, mouthparts and food are similar to that of adults. Both nymphs and adults share the same habitat. They lack wings and external genitalia. Wing buds externally appear in later instars. The genitalia development is gradual. The nymphs closely resemble the adults with successive moults. e.g. cockroach

Holometabola (Complete metamorphosis): life stages: egg-larva-pupa-adult

The majority of the insects undergo complete metamorphosis. The larva differs generally in form from the adult. Compound eyes are absent in the larva. Lateral ocelli or stemmata differ from adults. Wing bud development is internal. It transforms into a pupa. In the pupal stage the larval tissue disintegrates and adult organs develop. e.g. butterfly and moth, beetle, bees, wasps, flies.

Diapause in insects

The period of suspended development at any stage of the life cycle, under adverse conditions accompanied by greatly decreased metabolism is called diapauses. This phenomenon is governed by a variety of external and internal factors. This is an adaptation to tide over unfavourable environmental conditions like cold, drought, humidity, nutritional deficiencies. The other factors which are responsible for the diapauses are endocrine glands.

1. Diapause caused by a lack of brain hormone and moulting hormone It takes place in larval and pupal stage.
2. Diapause caused by a lack of brain hormone and juvenile hormone and is found in adult diapause.
3. Diapause caused by inactivity of neurosecretory cells of corpora allata. It is found in early embryonic stage i.e. development of eggs.

TYPES OF LARVA AND PUPA

Larva (plural larvae)

Larva is an immature stage between the egg and pupal stage of an insect having complete metamorphosis. It is the active growing stage.

Types of larvae

There are mainly three types of insect larva namely oligopod, polypod and apodous based on the number of legs they have.

Oligopod

Thoracic legs are well developed. Abdominal legs are absent. There are two subtypes

A. Campodeiform

Body elongate, depressed dorsoventrally and well sclerotised. Head is prognathous. Thoracic legs are well developed. A pair of abdominal cerci or caudal processes is usually present. Larvae are generally predator and very active. E.g. Grub of antlion or grub of coccinellid beetle

B. Scarabaeiform

Body C shaped, stout and sub cylindrical. Head is well developed. Thoracic legs are short. Caudal processes are absent. Larva is sluggish, burrowing into wood or soil. E.g. Grub of rhinoceros beetle

Polypod or Eruciform

The body consists of an elongated trunk with large sclerotised head capsule. Head bears a pair of powerful mandible. Two groups of single lensed eyes found on either side of the head constitute the visual organ. Three pairs of thoracic legs and five pairs of unsegmented abdominal legs or prolegs are present. Thoracic legs are segmented and they end in claws which are used for holding on to the leaf. Base of the proleg is called as planta. Abdominal segments three to six and ten typically bear prolegs. E.g. Larva of moth and butterfly

Apodous

The larvae are without appendages for locomotion. Based on the degree of development and sclerotization of head capsule there are three sub types:

A. Eucephalous

Larva with well developed head capsule with functional mandibles, maxillae and antennae. E.g. larva (wriggler) of mosquito

B. Hemicephalous

Head capsule is reduced and can be withdrawn into thorax. E.g. Larvae of robber fly

C. Acephalous

Head capsule is absent. Mouthpart consists of pair of protrusible curved mouth hooks and internal sclerites. They are also called vermiform larva. E.g. Maggot of house fly

Pupa

It is the resting and inactive stage of all holometabolous insects which comes between larval and adult stage. During this stage insect is incapable of feeding and is quiescent. There are three main types of pupa

Obtect

In obtect pupae, the insect's appendages are fused or "glued" to the body wall as the exoskeleton hardens. Obtect pupae occur in many of the Diptera (midges, mosquitoes, crane flies, and other members of the suborder Nematocera)

Exarate

Exarate pupae are just the opposite of obtect pupae; the appendages are free, and they can move (though usually remain inactive). Movement is usually limited to the abdominal segments, but some can also move their appendages. An exarate pupa usually lacks a cocoon, and looks like a pale, mummified adult (according to Borror and Delong's Introduction to the Study of Insects). Most pupae fall into this category. E.g. pupa of rhinoceros beetle

A. **Decticous**

Decticous pupae have articulated mandibles, which they may use to chew through the pupal cell. Decticous pupae tend to be active, and are always also exarate, with free appendages.

B. **Adecticous**

Adecticous pupae lack functional mandibles, and cannot chew their way out of the pupal case or bite in defense. The mandibles are attached to the head in such a way as to render them immobile.

Coarctate

Coarctate pupae are covered in a membrane called a puparium, which is actually the hardened cuticle of the final larval instar. These pupae have free appendages. Coarctate pupae are found in many families of Diptera (suborder Brachycera).

DIGESTIVE SYSTEM OF GRASSHOPPER

The alimentary canal of insects is a long, muscular and tubular structure extending from mouth to anus. It is divided into three regions viz., Foregut, midgut and hindgut.

Foregut (Stomodeum) : It is ectodermal in origin. It contains preoralcavity, pharynx, oesophagous, gizzard. Distal part of oesophagous is called crop which acts as food reservoir. Gizzard or proventriculus is the posterior part of foregut.

Midgut (mesenteron): It is endodermal in origin. It is made up of three types of cells,secretory cells, globlet cells and regenerative cells.It contain different parts like, peritrophic membrane, gastric caecae, pyloric valve and filter chamber. Filter chamber is a complex organ in which two ends of ventriculus and the beginning of hindgut are enclosed in a sac. It helps in osmoregulation.

Hindgut (proctodeum): It is ectodermal in origin. It is differentiated into three regions viz., ileum, colon and rectum. The main functions of hindgut are absorption of water,salt and other useful substances from the faeces and urine.

Gut physiology: Primary functions of the gut is to digest the ingested food and absorb the metabolites. Digestion process is enhanced with the help of enzymes produced by digestive glands and microbes housed in special cells.

Salivary glands: Functions:

1. To moisten and to dissolve food
2. To lubricate mouthparts
3. To add flavour to gustatory receptors
4. Saliva contains amylase for the digestion of starch.

5. In honey bee saliva contains invertase for sucrose digestion.
6. In jassid saliva contains lipase and protease for lipids and protein digestion. It also contains toxins which produces tissue necrosis.
7. In plant bug saliva contains pectinase which helps in stylet penetration.
8. In mosquito saliva contains anticoagulin.
9. In gall producing midges saliva contains Indole Acetic acid(IAA).
10. In disease transmitting vectors the saliva paves way for the entry of pathogens.

Absoption: In many insectsabsorption of nutrients occurs through microvilli of midgut epithelial cells by diffusion. Absorption of water and ions occur through rectum.

EXCRETORY SYSTEM OF GRASSHOPPER

Removal of waste products of metabolism, especially nitrogenous compounds from the body of insects is known as excretion. Following are the excretory organs:

1. Malpighian Tubules: Thin, blind- ending tubules, originating near the junction of mid and hindgut, predominantly involved in regulation of salt, water and nitrogenous waste excretion. This structure was discovered by Marcello Malpighi.
2. Nephrocytes: Cells that sieves the haemolymph for products that they metabolize.
3. Oenocytes: These are specialized cells of haemocoel, epidermis or fat body.
4. Tracheal system: The insect gas exchange system, tracheae and tracheoles.
5. Rectum: The posterior part of hind gut.

Physiology: The malpighian tubules produces an isosmotic filtrate which is high in K^+ and low in Na^+ with cl^- as major anion. The active transport of ions especially K^+ into the tubule lumen generates an osmotic pressure gradient for the passive flow of water. Sugars and most amino acids are also passively filtered from the haemolymph via junction between the tubule cells, where as amino acids and non-metabolizables and toxic organic compounds are actively transported into the tubule lumen. Sugar is reabsorbed from the lumen and returned to the haemolymph. The continuous secretory activity of each malpighian tubule leads to a flow of primary urine from its lumen towards and into the gut. In the rectum, the urine is modified by removal of solutes and water to maintain fluid and ionic homeostasis of the body.

Nitrogenous excretion: Terrestrial insects excrete waste products as uric acid or certain of its salts called urates which are water insoluble and requires less amount of water for waste product removal. This type of excretion is called Uricotelism. In aquatic insects ammonia s the excretory product, which is freely soluble in water and requires more amount of water for waste product removal. This type of excretion is called Ammonotelism.

Cryptonephry: The distal end of the malpighian tubules are held in contact with the rectal wall by the perinephric membrane, which is concerned either with efficient dehydration of faeces before their elimination or ionic regulation.e.g. adult beetle, larva of moth and butterfly and larva of saw fly.

CIRCULATORY SYSTEM OF GRASSHOPPER

The circulatory system comprises mainly the blood and the tissues and organs which cause its circulation through the body.

Haemolymph and its functions

Haemolymph contains a fluid called plasma and cellular fractions called haemocytes. Plasma is an aqueous solution of inorganic ions, lipids, sugars, amino acids, proteins, organic acids and other compounds. pH is usually acidic (6.7). Water cotent is 80-90%. Carbohydrate is in the form of trehalose sugar. Blood cells are of several types and all are nucleate.

Functions of haemolymph:

1. Lubricant
2. Hydrolic medium: hydrostatic pressure developed due to blood pumping is useful in ecdysis, wing expansion in adults, adult emergence from puparium and maintenance of body shape in soft bodied caterpillars.
3. Transport and storage
4. Protection
5. Thermoregulation
6. Reflex bleeding

Organs of circulatory system

Dorsal vessel: dorsal vessel runs along the dorsal midline, just below the terga, for almost the whole length of the body. It is divided into two regions, heart and aorta. Heart is situated within the pericardial sinus by means of suspensory and elastic filaments attached to the abdominal terga and frequently to the dorsal diaphragm. It may be divided by successive constrictions into a series of chambers. The blood enters the heart through lateral inlets called ostia, a pair of which is situated at each constriction. Aorta is the anterior prolongation of the dorsal vessel and it functions as the principal artery of the body. It extends forward through the thorax and terminate into the head near the brain.

Accessory Pulsatory Organs

They are sac like structures situatedin various regions of the body and connected with the haemocoel which are concerned with the circulation through the appendages. In hemiptera special pulsatile organs are present in legs. In periplaneta and Lepidoptera it is at the base of each antenna.

Physiology of circulation

The principal pulsatory organ is heart whichcontinuously undergoes rhythmic contraction (systole). The chambers of heart contract one after another from behind forward. The blood from the pericardial sinus enters the chambers through the ostia during diastole and during systole the ostial valves close and the blood flows into the chambers infront. Thus the blood is propelled forward into the aorta and is emptied in the cavity of the head and from here it flows into perivisceral sinuses. The blood reaches into the appendages and wings by the accessory pulsatory organs and finally comes to the pericardial sinus.

RESPIRATORY SYSTEM OF GRASSHOPPER

The insect possess tracheal system i.e. a system of open tubes called trachea and tracheoles through which air is brought directly to the tissue cells. The basic structural components of tracheal system is the trachea which opens to atmosphere by paired pores called spiracles. Trachea and tracheoles: The tracheae are invagination of ectoderm i.e. origin of trachea is ectodermal. Externally trachea are covered by polygonal cells secreted by cuticle forming intima. This intima forms spirally thicken part of trachea whose each ring is called taenidium which strengthen the trachea and ensure that it remains round and open even under condition of bending and pressure. The trachea divides and redivides becoming smaller ans smaller finally each ends in a cluster of minute branches, the tracheoles. Tracheoles are less than 1 μm in diameter and they end blindly and closely contact the respiring tissues.taenidia is absent in it.

Spiracles: These are the paired lateral modified part of tracheal system and varies from species to species. In pterygote spiracles open into specious channel called atrium but attrium is absent in apterygotes. Usually two pairs of spiracles are found on thorax and 5-8 pairs on abdomen.

Types of Spiracle: According to position and number of function spiracles are of following types.

1. Polypneustic Type: It has at least 8 functional spiracles
   i. Holopneustic – 10 (2 + 8) e.g. grasshopper
   ii. Peripneustic – 9 (1 + 8) e.g.Caterpillar
   iii. Hemipneustic – 8 (1 + 7) e. g.
2. Oligopneustic Type : It has 1 or 2 functional spiracle
   i. Amphipneustic – 2 (1 + 1) e.g. maggot
   ii. Proneustic – 1 (1 + 0) e.g. Puparium
   iii. Metapneustic – 1 (0 + 1) e.g. wriggler
3. Apneustic Type: No functional spiracle. In this situation the respiration is carried out by following provisions:
   i. Provision of hydrofuse e. g. Notonecta
   ii. Provision of perispiracular glands e. g. Caddis fly
   iii. Provision of long crowny hair e. g. Dytiscus larva
   iv. Provision of respiratory siphon e. g. Mosquito larva
   v. Provision of filamentous gills e. g. damsel fly nymph

Air Sac: Certain portions of the trachea may be elliptical instead of round and have weak taenidia or non at all. These elliptical portions form sacs which can be flattened by an increase in blood pressure or by bending. Airsac acts as oxygen reservoir. Provide buoyancy to flying. Acs as sound resonstors and heat insulators.

Mechanism of respiration

Rhythmic movement occrs in two ways:

i. Expiration
ii. Inspiration

During inspiration (taking oxygen from atmosphere) abdomen expands and thoracic and anterior first two abdominal spiracles open and during expiration these anterior spiracles close with the opening or the posterior abdominal spiracles. The mechanism of movement of air through the tracheal system partly by diffusion and partly by active ventilation. Oxygen passes through the length of the trachea and tracheoles and finally into the tissues and by which CO_2 is eliminated along the reverse path. These gases are conveyed by diffusion, with the help of some mechanical ventilation in certain insect.

NERVOUS SYSTEM OF GRASSHOPPER

The basic component in nervous system is the nerve cell or neuron, composed of a cell body with two projections (fibres) the dendrites or dendrons that receive stimuli and the axon that transmits information.Axon may have lateral branches called Colleteral and terminal arborisation and synapses. Types of neuron:

A. On structural basis
   i. Monopolar: Neuron with a single axon
   ii. Bipolar: Neuron with an axon and a dendrite
   iii. Multipolar: Neuron with an axon and many dendrites
B. On functional basis
   i. Sensory neuron: It conducts impulse from sense organs to central nervous system
   ii. Motor neuron: It conducts impulse from CNS to effector organ
   iii. Inter/association neuron: It inter-links sensory and motor neurons.

Nervous system can be divided into three major subsystems:

i. Central Nervous System (CNS)
ii. Visceral Nervous System (VNS)
iii. Peripheral Nervous System (PNS)

Central Nervous System: It contains double series of nerve centres (ganglia). These ganglia are connected by longitudinal tracts of nerve fibres called connective and transverse tracts of nerve fibres called commissures. CNS includes the following:

a. Brain: Formed by the fusion of first three cephalic neuromeres. Protocerebrum: Large, innervate compound eyes and ocelli. Deutocerebrum: Found beneath protocerebrum and innervate antennae. Tritocerebrum: Bilobed, innervate labrum.
b. Ventral nerve cord: median chain of segmental ganglia beneath oesophagus.
c. Sub oesophageal ganglia: Formed by the last three cephalic neuromeres which innervate mandible, maxillae and labium.

d. Thoracic ganglia: Three pairs found in the respective thoracic segments, largest ganglia, innervate legs and muscles.
e. Abdominal ganglia: Maximum eight pairs present and number varies due to fusion of ganglia. Innervate spiracles.
f. Thoracic abdominal ganglia: Thoracic and abdominal ganglia are fused to form a single compound ganglia. Innervate genital organs and cerci.

Visceral nervous system: The VNS consists of three separate systems as follows:
1. The stomodeal which includes the frontal ganglia and associated with the brain,aorta and foregut

2. Ventral visceral: associated with the ventral nerve cord

3. Caudal visceral: associated with the posterior segments of abdomen.

Peripheral nervous system: The PNS consists of all the motor neuron axon that radiate to the muscles from the ganglia of the CNS and visceral nervous systemplus the sensory neurons of the cuticular sensory structures that receive mechanical, chemical,thermal or visual stimuli from an environment.

REPRODUCTIVE SYSTEM OF GRASSHOPPER

In insects male and female sexes are mostly separate. Some insects are hermaphrodite in which male an dfemale gonads are present in one organism e.g. Cottony cushion scale.

Female Reproductive system: The main function of the female reproductive system are egg production and storage of male’s spermatozoa until the eggs are ready to be fertilized. The female reproductive system consists of paired ovaries, which empty their mature oocytes (eggs) via the Calyx into the lateral oviduct which unite to form the common oviduct. The gonopore (opening) of common oviduct forms a cavity, the genital chamber.It is also known as the bursa copulatrix. Its external opening is the vulva. Two types of ectodermal glands open into the genital chamber. First is the spermatheca which stores spermatozoa until they are needed for egg fertilization. Spermatheca is a single and sac like structure with a slender duct called spermathecal gland. This glands provide nourishment to the spermatozoa. The second type of ectodermal gland, is accessory glands which opens in the genital chamber.

Male Reproductive system: The main function of the male reproductive system are the production and storage of spermatozoa and their transport in a viable state to the reproductive tract of the female. The male reproductive system consists of paired testes, vas deferens expands posteriorly to form a sperm storage organ or seminal vesicle. The paired vasa deferentia unite to form ejaculatory duct. Tubular paired accessory glands are associated with vasa deferentia or ejaculatory duct. Its function is to produce seminal fluid and spermatophores.

Secretary (Endocrine)

These are the glands without duct which are as follow:

1. Neurosecretary cells: A pair of median neuro-secretary cells and lateral neuro-secretary cells are present. The axons of these neuro-secretary cells form two pairs of nervi corpora cardiaci ending in carpora cardiaca. This structure influence the functioning of other endocrine glands.

2. Carpora cardiac: It consists paired bodies fused in middle and have both nervous tissues and glandular tissues. It acts as a conventional storage and release organ for neuro-secretary cells. It controls heart beat and regulate trehalose level in haemolymph.

3. Corpora allata: It is a paired gland attached to corpora cardiac and secretes juvenile hormone (JH) there by inhibit metamorphosis. It is needed for egg maturation and functioning of male accessory glands. JH is analogues interfere with insect development. Precocene is an anti JH which induce precocious metamorphosis and death in insects.

4. Prothoracic glands: Paired glands present in ventolateral part of prothorax of larva and is degenerated in adults. It secretes the moulting hormone ecdysone. Neurosecretory cells activate prothoracic glands to secrete ecdysone.

5. Weismann's ring: It is formed by the fusion of carpora cardiac, corpora allata, prothoracic glands and hypopharyngeal ganglion to secrete puparium hardening hormone. Present in maggots of Dipteran flies.

TYPES OF REPRODUCTION IN INSECTS

Ovoparity: Majority of female insects are oviparous, lay eggs.e.i. moths, grasshoppers.
Viviparity: Initiation of egg development takes place within the mother insect. Four main types:

1. Ovoviviparity: Fertilized eggs containing yolk are incubated inside the reproductive tract of the female and hatching of egg occur just prior to or soon after oviposition e.g. thrips, some cockroaches, few beetles and flesh fly.
2. Pseudoplacental viviparity: This occurs when a yolk deficient egg develops in the genital tract of the female and a special placenta like structure nourishes the developing embryos.e.g. some earwigs, psocids and polytenid bugs.
3. Haemocoelous viviparity: Embroys developing free in the female's haemolymph.
4. Adenotrophic vivipaity: When a poorly developed larva hatches and feeds orally from accessory gland (milk gland) secretion within the uterous of the mother.e.g. tsetse flies, louse bat flies.

Parthenogenesis: Reproduction without fertilization is Parthenogenesis. E.g.aphids, stick insect male bees.

Polyembryony: This involves the production of two or more embyos from one egg.e.g. parasitic insectse.g. *Platygaster*.

Paedogenesis: Gonads develop and give birth to young one by parthenogenesis.i.e. reproduction by immature insects. Gall midge.

SENSORY ORGNS

The different types of sense organs are: **1. Mechanoreceptors** (detect mechanical forces)

i. Trichoid sensilla: hair like little sense organs. Sense cell associated with spur and seta. These cells are sensitive to touch and are located in antenna and mouth parts(trophi).
ii. Campaniform sensilla (Dome sensilla): Terminal end of these sensilla is rod like and inserted into dome shaped cuticula. These cells are sensitive to pressure and located in leg joints and wing bases.
iii. Chordotonal organ: These cells receive vibrations. These organs are interoceptors attached to both ends of body wall. All adult insects and many larvae have a complex chordotonal organ called Johnston's organ situated within the second antennal segment (Pedicel). This organ senses movements of antennal flagellum. It also functions in hearing in some insects like mosquitoes and midges.
iv. Chordotonal organ located in the proximal tibia of each leg, used to detect substrate vibration (except coleopteran and diptera).

2. Chemoreceptors (detect smell and taste)

Insect chemoreceptors are sensills with one pore (uniporous) or more pores (multiporous). Uniporous chemoreceptors mostly detect chemicals of solid and liquid form by contact and are called as gustatory receptor. They are found in antenna. Multiporous chemoreceptors detect chemicals in vapour form at distant by smell and are called olfactory receptor. They are found in trophy and tarsi.

3. Photoreceptors (detect light energy):

a. Compound eyes: The compound eye is made up of many individual units called ommatidia. Each ommatidium is marked externally by a hexagonal area called facet. Compound eye is made up of two parts, optic part and sensory part. Optic part contains a cuticular lens and crystalline cone covered by primary pigment cells. Function of the optic part is to gather light. Sensory part contains six to ten visual cells called retinular cells covered by secondary pigment cells which collectively secrete a light sensitive rod at the centre called rhabdom. Rhabdom contains light sensitive pigments called rhodopsin. Each ommatidium is covered by a ring of light absorbing pigmented cells, which iosolates an ommatidium from other. Nerve cells are clustered around the longitudinal axis of each ommatidium.

Types of ommatidia

i. Apposition type: It is found in diurnal insects. Due to presence of primary pigment cells light cannot enter the adjacent cells. So, the mosaic vision formed is very distinct. The image formed by the compound eye is of a series of opposed points of light of different intensities.
ii. Super position type: primary pigment cells are absent allowing light to pass between adjacent ommatidia. Image formed in this way are indistinct, bright and blurred. This type is seen in nocturnal and crepuscular insects.

Lateral ocelli (stemmata): Visual organs of holometabolous larva. Structure is similar to ommatidium. It helps to detect form,colour and movement and also to scan the environment.

Dorsal ocelli: Visual organs of nymph. It contains a single corneal lens with many visual cells individually secreting the rhabdomere. It perceives light to maintain diurnal rhythm and is not involved in image perception.

Part- II

INSECT ECOLOGY

Ecology is one of the disciplines of a much broader area of action covered by environmental science. Ecology concerns the processes dealing with what limit life, how living things interact with their surroundings and how living things make use of the resources.

Ecology, the term proposed by a German biologist "Ernst Haeckel" during the year 1869. The study of the interrelationships between organisms and their environment is termed "Ecology". According to different scientists the ecology has been defined as:

Standford(1907): Life needs and house keeping habits of an organism.

Clements(1916): Science of community.

Odum(1971): Study of organisms at home.

Peter Price (1975): Science of relationship of organisms to their nature.

Environment and its components

Environmental science, on other hand, deals with the application of this knowledge for managing the environment.

Clark etal. (1967)- defined the environment of the population as everything external to the population that influences its abundance and evolution.

According to Andrewartha and Birch (1954), the environment of an individual organism may be analysed into four components, viz., weather,other organisms, food and a place to live. The four components were said to comprise everything that might influence an organism's chance to survive and multiply.

Components of Environment

Weather: Temperature, Light, Humidity, Rainfall, Wind etc.

Food: Quality and quantity

Organisms: Plants and animals

Place: Habitat

EFFECT OF ABIOTIC FACTORS

Temperature:

It has got a profound influence on the life cycle of insects by affecting the number of generations. Normal life activities go on smoothly at a specific temperature called optimum range of temperature. The rate of chemical reactions and metabolic processes are influenced by temperature. Insect enter diapause if the temperature is below optimum called hibernation or above optimum called aestivation.

Influence on fecundity: e.g. (i) Diamond back moth (DBM) lays more eggs at a temperature of 18^0C than 22^0C.

(ii) Grasshopper lays 20 to 30 times more eggs at 32^0C than 22^0C.

(iii) Oviposition of bedbug is inhibited at 8^0C to 10^0C.

Other effects:

(i) High temperature induces more early shoot borer attack in sugarcane.
(ii) Larval period of sugarcane internode borer is shortened 16-24 days in summer and prolonged 141-171 days during winter.
(iii) Desert locust *Shistocercs gregaria* swarms at 17^0C to 20^0C.

Light:

The influence of light on some insects are:

(i) In ahids short day length produces sexual forms and long day length produces asexual forms like parthenogenetic viviparous reproduction.
(ii) Frut flies, Tephritids lay eggs only in light.
(iii) Codling moth, cotton bollworm, *Earias* spp.Red hairy caterpillar oviposit in dark.

Humidity:

Insect exhibit the phenomenon of humidity preferendum also like that of temperature. The have a tendency to congregate within a narrow range of humidity and that range is the preferred humidity.e.g.

(i) High humidity induces the incidence of BPH in rice and aphids in other crops.
(ii) Termites usually move towards a zone of high humidity when subjected to the the slightest desiccation.Termites showed a humidity preferendum of 90-95% RH and they live longer at 100% RH under starved condition.
(iii) Migratory locust, *Locusta migratoria* failed to produce eggs at 40% RH but at 70% RH, it sexually matures.
(iv) Rice weevil, *Sitiphilus oryzae* fecundity is less at 34% RH and maximum at 70% RH.

Rainfall:

Some of the effects of rainfall on the biology of insect.eg.:

(i) In red hairy caterpillar and cutworms rainfall is essential for adult emergence and pupation..
(ii) Excess rainfall brings the white grubs to soil surface so that get predated by birds.
(iii) Excess rainfall controls aphids and DBM.
(iv) Intermittent low rainfall increases BPH and thrips incidence in rice.

Wind:

Wind is of great value to insect displacement and therefore, affect population changes by influencing the numbers into or out of an area.

(i) Mostinsects will not take flight when the speed of wind exceeds the normal flight speed.
(ii) Strong flying insects tend to fly with the winds during migration and are displaced long distances as in case of spruce budworm moth.
(iii) Aphids and leafhoppers are being blown thousands of kilometres.
(iv) Helicoverpa adults fly up to 90 Km with the help og wind current.
(v) Air movement may be directly responsible for the death of insects.
(vi) Severe wind coupled with heavy rains may cause motality.

Topographic factors:

Besides mountains, lake,sea etc. Also act as physical barrier for the spread.

Soil type:

It plays an important role in the multiplication of insect species. Wireworms multiply in heavy clay soil with poor drainage and white grubs multiply in loose sandy soil with better drainage.

Water:

Standing water helps in the multiplication of insects like mosquitoes and certain beetles. Running water stream is preferred by odonates and cadis flies etc.

EFFECT OF BIOTIC FACTORS

Food:

Quality and quantity of food play an important role in its survival, longevity, distribution, reproduction and speed of development, etc.

Quantity of food:

When thereis relatively small number of individuals per unit quantity of food, there is enough for all to grow to adulthood but in the scarcity of food, only those develop rapidly to become adulthood, while the slower ones do not develop. More than one species consuming the same food will naturally reduce the total amount available for any of them.

Quality of food:

Egg production, larval development, longevity and size of insects may be greatly influenced by the quality of food. Many insects species store sufficient nutrients during the larval stage to accomplish adult activities. The queen of honey bee and termites lay eggs for almost all of their adult lives and require food constantly. The differences between workers and queen honeybee depend entirely on the diet that each receives during larval development. They feed workers larvae only for three days and queen larvae continue to be fed on royal jelly. Changes in the quality of food induce the appearance of winged forms and migratory behaviour in aphids.

Competition

Competition includes all those interactions among different species which adversely affect their growth and survival. The interaction between the individuals of the same speciesis called intraspecific and between those of different species is called inerspecific.

Intraspecific intractions are the following:

Aggregation:

Aggregation refers to the tendency of some insects to concentrate in numbers larger than found in normal distribution and congregate under various circumstances by their own movements e.g. homopterans (species of membracids).

Concurrence:

They crowd together in mass assemblance at one time for feeding or hibernating e.g. Coccinelids, Pieris butterflies dragonflies armyworms.

Cannibalism:

It takes place between members of the same species. Large larvae and adults may feed on eggs and small larvae of their own species or older adults encounter the younger stages.

Association of the sexes:

The sex ratio in insects plays an important part in the build up of their population at the same temperature. If the sex ratio of a house fly at ordinary temperature is 1:1, then there will be 2×60^7 flies at the end of breeding season.

Parental care:

It includes care of eggs and broods also, provision of larval food either on the plant itself or providing food material from outside.e.g. dung beetle, earwings and mole cricket.

Social life:

Ants, termites, wasps and honeybees live in a family colonies that have a division of labour among individuals and an interchange and sharing of food and other things among members of the colony.

Interspecific intractions are the following:

Commensalisms: It is an unbalanced relationship in which one of the partner is benefitted and the other remaining unbenefitted and unharmed.e.g.Staphylinid beetles inhabit nests of ants as commensals.

Mutualism or Symbiosis: It is the relationship in which both the partners are benefitted e.g.Ants feed on honeydew secreted by aphid actively produce 'milk' to obtain honeydew.Insect that feed on pollen and nectar have a mutualistic relationship to their plant hosts as they carry it to the next flower and thus helps in pollination.

Parasitism:

It is the relationship in which one species benefits at the expense of another.e.g. facultative parasites like biting flies, lice and fleas. Parasitoids are mostly Hymenoptera and Diptera (especially Tachinidae).

Predatism:

A predator kills but never eliminates the prey completely. Preying mantis prey on many insects like larvae, nymphs and leaf hoppers.*Crysoperla* on aphids ,jassids and *Coccinella* on aphids.

Natural enemies includes (a) parasites and (b) predators.

Environmental resistance

The sum total of all factors in an environment that tend to reduce the rate of multiplication of an insect is known as environmental resistance. The major factors responsible for the environmental resistance are physical, chemical, nutritional, host plant and biotic factors.

Physical factors include temperature, light and moisture and water. The physical condition in a locality influence the rate and development of insects.

Chemical factors: concentration of O_2 and CO_2 in the given medium is considered as chemical factors.Chemical present in the host decides the host selection and make an insect monophagous,oligophagous and polyphagous.Amino acid and asparagin decides the development of BPH in rice.

Nutritional factor: Availability of food regulates population abundance and influencelife cycle, sex ratio and fertility factors.

Host plant associated factors: Plant characters like thorn, wax, hairiness and thick cuticle interferes the normal feeding and oviposition.

Biotic factors includes parasites and predators.

Part III

CATEGORIES OF PEST

Pest: Any animal which is noxious, destructive or troublesome to man or his interests.

Categories of pests:

Based on occurrence

Regular pest: One occurring more frequently on a crop having close association. E.g.Rice stem borer, Brinjal shoot and fruit borer etc.

Occasional pest: One occurring infrequently in those causing damage at irregular interval with on close association.e.g.caseworm in rice, mango stem borer.

Seasonal pest: One occurring during a particular part of the year or season in particular crop,year after year.e.g.Red hairy caterpillar on ground nut, mangohoppers during flowering season.

Persistent pest: One occurring on a crop almost throughout the year and is very difficult to control.e.g.Thrips in chilli, mealy bug in guava.

Sporadic pest: One occurring in a few isolated localities.e.g.Coconut slug caterpillar, slug caterpillar on castor and rice gundhi bug etc.

Based on level of infestation

Epidemic pest: Occurrence of pest in a severe form in a region or locality at particular season or time.e.g.BPH in Tanjore during October and November.

Endemic pest: Occurrence of pest in a low level in few pockets or confined to a particular area..BPH in North Bihar.Cutworm in Mokama.

Based on the loss

Major pest: Insects which cause a loss of 10% or more of yiel are called as major pests.

Minor pests: Those which normally cause a loss ranging from 5-10% (less than 10%).

Key pests: A pest which causes major damage every season unless controlled is regular as key pests.

Potential pests: These pests normally cause negligible damage but may become highly destructive resulting from some disturbance in the environment and the consequent increase in their number e.g. armyworm on wheat.

The status of the pest can be assessed by observing the cost – benefit ratio.

INTEGRATED PEST MANAGEMENT - DEFINITIONS AND PRINCIPLES

Basis for IPM

Losses caused by insects accounts to nearly Rs.50,000/- crores annually i.e. 20 is lost. Why? there are 120 agro-climatic zones. Out of this, most of this area comes under dry land farming. But this produces 70 per cent of Agricultural produce. When the concept of green revolution came, they identified the areas of assured irrigation and technologies were identified to increase production in the assured irrigation areas. Another change was the introduction of high yield crop varieties. The varieties had very high potential and with the high inputs of fertilizer, water and pesticides they could yield substantially very high yields. But with the introduction of high yielding varieties, there were many problems of pests and diseases. The application of potential synthetic pesticides could control the pests and diseases in the initial stage. The farmers entice enormous monitory return. So the farmers still intensified the cultivation, they went in for higher inputs, they could get higher yield for 2 or 3 years. But, at one stage, the pest became to react i.e. there is always a competition between plant, pest and human. The pests overcome the stress and able to produce biotypes and became resistant. The insecticides that initially controlled the pest were not able to control the pest subsequently. Then the farmers increased the dosage and interval is shortened and combination of pesticides used. All these means lead to aggravation of pests. Even with all these means the pest was not controlled and a stage has come where the cost of input was increased than the yield. Now people thought to evolve new methods which are ecologically sound, safe i.e. input should be appropriate, pesticide should be proper, also introduced cultural methods, physical methods, need based methods based in ETL, how resistant varieties can be introduced, how biological agents can be introduced and other non conventional methods including botanicals, attractants repellents, etc. So they wanted to

integrate the possible methods either for a single pest or for all pests of a crop. This is the basis for IPM.

IPM definitions: There are many definitions

Barlett (1956) - defined integrated control as blending of biological control agents with chemical control interventions.

Geier and Clark (1961) - have called this conception of pest control the protective management of noxious species or pest management.

Before the development - and acceptance of pest management, pest technology focused on control rather than management.

NAS (1969) (National Academy of Sciences) came with the following definition.

All the available techniques are evaluated consolidated into a unified programme to manage pest populations so that economic damage is avoided and adverse side effects on the environment minimized.

The technology should not upset ecological balance.

Definition IPM definition by FAO (1967)- Integrated Pest Management (IPM) is a system that, in the context of associated environment and population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury.

IPM definition by Luckmann and Metcalf (1994)- IPM is defined as the intelligent selection and use of pest control tactics that will ensure favourable economical, ecological and sociological consequences.

Pedico (1989) - defined pest management as a comprehensive pest technology that used combined means to reduce the status of pest to tolerable levels while maintaining a quality environment.

The following objectives are derived from the definition.

1. It proposes that several techniques be employed to alleviate problems, rather than relying on a single tactic (for eg. insecticides alone).

2. The main objective of the approach is to reduce pest status.

3. Although reducing status may be achieved by killing pests, killing is not the objective, preventing economic loss is. Indeed, pest status also may be reduced by avoiding or repelling pests or by reducing their reproductive rates.

4. Another implication is that pest populations or their effects should be reduced to tolerable levels.

- Tolerance means that humans should accept the presence of pest species, although at levels that are not economically important. This aspect admits that complete elimination of pests

may not be feasible or even desirable. Particularly, this acceptance of pest presence sets pest management apart from pest control.

5. Finally, the capstone objective of pest management is the maintenance of quality environment. This objective clearly refers to conservation, and it includes quality of both cropping and non-agricultural environments (air, water, soil, wild life and plant life). The principles of pest management emphasize that cropping systems behave similarly to managed and natural systems i.e. they have diversity of interacting elements like natural insect and weed enemies that influence ecology of the crop environment. By maintaining the quality of this environment, lasting solutions can be achieved.

IPM consists of the following components

Apple et al. (1979) enumerate the component of pest management in agriculture as follows:

i. Identify the pests to be managed in the crop production system

ii. Define the management unit. i.e. management practices

iii Developing pest management strategy.

iv. Develop reliable monitoring techniques.

v. Establish economic thresholds and

vi. Evolve descriptive and predictive models.

The important points that are necessary for pest management as per Geier is as follows:

i. To determine how the life system of pest operates and how the systems modified to reduce the numbers below ETL.

ii. Apply the biological knowledge and technology to attain the desired modification. These two together forms applied ecology.

iii . Devising procedures for pest control which will suit the correct technology which will be compatible with the environment and also economical. The technologies will be economic and socially acceptable or social acceptance. Our final aim is to bring down the pest below ETL.

Patterns of crop protection

Smith (1969) has classified world wide pattern of crop protection in the cropping system into five phases.

eg. Problem of Helicoverpa in AP, Punjab than Tamil Nadu

Phases

1. Subsistence phase
2. Exploitation phase
3. Crisis phase
4. Disaster phase and

5. IPM phase

Subsistence phase

In the initial stages, there was one crop / year. The local varieties were used. High yielding varieties / hybrids were not available. There were no improved methods like agronomic practices; fertilizer application etc., there was no organized pattern of crop protection. The agriculture was done in marginal lands and the yields were very low. In fact the produce was utilized within the same village either consumed or exchanged for other materials in the same village.

Exploitation phase

After some time, people want to export the commodities from one village to other. Now crop varieties were developed. The area under the crop was increased. New markets were formed i.e. There was an exploitation of the crop and its produce under this situation. New pest control programmes were formulated.

Most of the pest control programmes has a single method of control i.e. chemical control. So there was an intensive cultivation, more of fertilizers, pesticides in a scheduled manner, not need based. Of course, in initial stage there was very good success. High yields were obtained and people sold the produce for high returns. In thisexploitation stage, chemical pesticides were used at the maximum stage.

Crisis phase:

For a few years there were good yields. But due to heavy insecticide application, there were many disturbances i.e. more frequent applications of pesticides and higher dosages are needed to obtain effective control. Insect populations often resurge rapidly after treatments, and pest population gradually becomes tolerant to the pesticide. At the same time insects that never cause damage or that are only occasional feeders become serious primary pests i.e. secondary pest outbreak was there, so the same dose used in the subsequence or exploitation phase, could not control the pest in crisis stage. Farmers use more frequent insecticides and several combinations of insecticides were used. All these lead to non desired level of pest control. But result in increase of input cost.

Disaster phase:

In this phase, the pesticide application costs were so high that a commercially profitable crop could not be raised. The residues in soil, plant, water, air became very high. The soil residues were passed onto the next crop to be grown and these residues were above the acceptable level. So the produce was not fit for processing consumption and the market for the produce also collapsed. So there is a collapse of the existing pest control programme.

IPM phase:

When the disaster phase was reached, the farmers and scientists evolved a method which is ecologically safer and economically sound. The methods are target oriented, ecologically safe and same time the methods should be adaptable. The main concept is to optimize the control measures rather than maximize it. From pest control moved to pest management.

Eg. Development of IPM for *Helicoverpa* in cotton

These phases are because of the ignorance of the farmers. If you take, IPM, it is not a new method, already followed by our ancestors.

Components of IPM

1. Surveillance and monitoring
2. Host plant resistance
3. Production technologies
4. Economic threshold levels
5. Selective insecticides
6. Biocontrol
7. Bio-ecology
8. Behavioural approaches

Principles and strategies of Integrated Pest Management

I. **Monitoring insect pests and natural enemies**

Pest surveillance and forecasting are essential tools in IPM which help in making management decision.

II. **Concepts of injury levels**

ETL (Economic threshold level) and EIL (Economic injury level) concepts are followed to reduce the use of insecticide and their impact on environment.

III. **Integration of pest control tactics**

Proper choice of compatible tactics and blending them so that each component complements the other.

The strategy of applying pest management tactics is similar to that of human medicine. i.e.

Preventive practice

Curative practice

Preventive methods of IPM include the following

a. Natural enemies
b. Host plant resistance
c. Cultural control
d. Legal control (Plant Quarantine)

Curative methods of IPM include the following

a. Physical and mechanical methods

b. Inundative method releasing biocontrol agents

c. Chemical insecticides, IGR

- Preventive methods can be used, irrespective of the level of pest incidence. It can be followed as a routine, even if the pest is at a low level.

- Curative methods have to be followed only when the pest attains economic threshold level (ETL).

Integration of different components of IPM There is two steps involved

i. Selection of appropriate method

ii. Integration of pest control method

i. Selection method: It could be preventive (prophylactic) or curative.

While selecting the method, it should possess following features:

a. It should be ecofriendly and cause minimum adverse effect on agro-eco system

b. There should not be any conflict between the methods

c. The methods should be least expensive

Integration of tactic

- Integrating management tactics is not simply adding a number of these tactics to form a program.

- Actual integration involves proper choice of compatible tactics and blending them so that each complements the other.

e.g. (1) Host plant resistance can be easily blended with crop sanitation

(2) Insecticide control is compatible with other preventive methods

(3) It is difficult to blend natural enemy release with others like pesticides

- Integration of tactics, requires interdisciplinary approach.

- A knowledge of other subjects like, nematology, plant pathology, microbiology, crop and farm management also required when we go upward in level of integration.

Constrains in IPM have been listed by IPM task force as follows:

i. Institutional constraint

IPM requires interdisciplinary approach to solve pest problem. Lack of coordination among different institution is a constraint. Research programme based on farmer's neem - is lacking.

ii. Informational constraint

Lack of information on IPM among farmers and extension worker.Lack of training on IPM.

iii. Sociological constraint

Some farmers feel it is risky to adopt IPM compared to use of pesticides alone. Our farmers are habituated to using more pesticides.

iv. Economic constraint

Lack of funds for training farmers and extension workers on the use of IPM.

v. Political constraint

-Vested interest associated with pesticide trade

- Pesticide subsidy by Government

These are the constraints for the implementation of IPM.

Options/strategies in IPM implementation

Acceleration of IPM implementation requires the following

i. Farmer's participation

Farmers must be encouraged to participate in IPM and give their views.

ii. Government support

Government can remove subsidies on pesticides and allot more fund for IPM implementation.

iii. Legislative measures

Suitable legislation (law) may be passed for adopting IPM by all farmers (IPM will be successful only if adopted on community basis).

iv. Improved institutional infrastructure

National level institution for implementation of IPM is a must. Data base on role of biotic and abiotic factors on pest population, crop yield are required.

v. Improved awareness

Awareness should be created at all levels on IPM i.e. Policy makers, farmers, consumers and general public. NGOs (Non Governmental Organisation) should be made aware of the advantages of IPM.

Objectives of pest management

1. To reduce pest status below economic injury level. Complete elimination of pest is not the objective.
2. To manage insects by not only killing them but by preventing feeding, multiplication and dispersal.
3. To use ecofriendly methods, which will maintain quality of environment (air, water, wild life and plant life)
4. To make maximum use of natural mortality factors, apply control measures only when needed.
5. To use component in sustainable crop production.

Requirements for successful pest management programme

1. Correct identification of insect pests
2. Life history and behaviour of the pest
3. Natural enemies and weather factors affecting pest population
4. Pest surveillance will provide above data
5. Pest forecasting and predicting pest outbreak
6. Finding out ETL for each pest in a crop
7. Need and timing of control measure - Decision
8. Selection of suitable methods of control
9. Analysis of cost/benefit and benefit/risk of each control measure
10. Farmer's awareness and participation
11. Government support
12. Consumer awareness on use of pesticides free products

TOOLS OR COMPONENTS OF INTEGRATED PEST MANAGEMENT

i. Cultural method or use of agronomic practices

1. Crop rotation
2. Crop refuse destruction
3. Tillage of soil
4. Variation in time of
5. Pruning or thinning
6. Fertilizer management
7. Water management
8. Intercropping planting or harvesting

9. Trap crop.

ii. Host plant resistance

- Antixenosis, antibiosis, tolerance

iii. Mechanical methods of pest control

1. Hand destruction
2. Exclusion by screens, barriers
3. Trapping, suction devices, collecting machine
4. Crushing and grinding

iv. Physical methods

1. Heat
2. Sound
3. Cold
4. Energy

v. Biological methods

1. Protection and encouragement of NE
2. Introduction, artificial increase and colonizing specific parasitoids and
3. Predators Pathogens on insects like virus, bacteria, fungi and protozoa
4. Use of botanicals like neem, pongam, etc.

vi. Chemical methods

1. Attractants
2. Repellents
3. Insecticides - OC, OP, carbamates, pyrethroids, etc.
4. Insect growth inhibitors
5. Chemosterilants

vii.Behavioural methods

1. Pheromones 2. Allelochemics

Viii.Genetic/biotechnology method

- Release of genetically incompatible/sterile pests - Transgenic plant

ix. Regulatory/legal method

- Plant/animal quarantine
- Eradication and suppression programme

HOST PLANT RESISTANCE - DEFINITION - TYPES AND MECHANISMS ECOLOGICAL AND GENETIC RESISTANCE

Host Plant Resistance (HPR)

Definition Those characters that enable a plant to avoid, tolerate or recover from attacks of insects under conditions that would cause greater injury to other plants of the same species (Painter, R.H., 1951). Those heritable characteristics possessed by the plant which influence the ultimate degree of damage done by the insect (Maxwell, F.G., 1972).

Types of Resistance

Ecological Resistance or Pseudo resistance

Apparent resistance resulting from transitory characters in potentially susceptible host plants due to environmental conditions.

Pseudoresistance may be classified into 3 categories

a. Host evasion Host may pass through the most susceptible stage quickly or at a time when insects are less or evade injury by early maturing. This pertains to the whole population of host plant.

b. **Induced Resistance** Increase in resistance temporarily as a result of some changed conditions of plants or environment such as change in the amount of water or nutrient status of soil

c. **Escape** Absence of infestation or injury to host plant due to transitory process like incomplete infestation. This pertains to few individuals of host.

Genetic Resistance

A. Based on number of genes - Monogenic resistance: Controlled by single gene Easy to incorporate into plants by breeding Easy to break also

- Oligogenic resistance: Controlled by few genes
- Polygenic resistance: Controlled by many genes
- Major gene resistance: Controlled by one or few major genes (vertical resistance)
- Minor gene resistance: Controlled by many minor genes.

The cumulative effect of minor genes is called adult resistance or mature resistance or field resistance. Also called horizontal resistance

B. Based on biotype reaction - Vertical resistance: Effective against specific biotypes (specific resistance) - Horizontal resistance: Effective against all the known biotypes (Non specific resistance)

C. Based on population/Line concept - Pureline resistance: Exhibited by liens which are phenotypically and genetically similar - Multiline resistance: Exhibited by lines which are phenotypically similar but genotypically dissimilar

D. Miscellaneous categories

- Cross resistance: Variety with resistance incorporated against a primary pest, confers resistance to another insect.

- Multiple resistance: Resistance incorporated in a variety against different environmental stresses like insects, diseases, nematodes, heat, drought, cold, etc.

E. Based on evolutionary concept

- Sympatric resistance: Acquired by coevolution of plant and insect (gene for gene) Governed by major genes

- Allopatric resistance: Not by co-evolution of plant and insect. Governed by many genes

Mechanisms of Resistance

The three important mechanisms of resistance are - Antixenosis (Non preference) - Antibiosis - Tolerance

Antixenosis: Host plant characters responsible for non-preference of the insects for shelter, oviposition, feeding, etc. It denotes presence of morphological or chemcial factor which alter insect behaviour resulting in poor establishment of the insect. e.g. Trichomes in cotton - resistant to whitefly Wax bloom on carucifer leaves - deter feeding by DBM Plant shape and colour also play a role in non preference Open panicle of sorghum - Supports less Helicoverpa

Antibiosis Adverse effect of the host plant on the biology (survival, development and reproduction) of the insects and their progeny due to the biochemical and biophysical factors present in it. Manifested by larval death, abnormal larval growth, etc. Antibiosis may be due to - Presence of toxic substances - Absence of sufficient amount of essential nutrients - Nutrient imbalance/improper utilization of nutrients

Chemical factors in Antibiosis - Examples

Chemicals present in plants Imparts resistance against

1. DIMBOA (Dihydroxy methyl benzoxazin): Against European corn borer, Ostrinia nubilalis
2. Gossypol (Polyphenol): *Helicoverpa armigera* (American bollworm)
3. Sinigrin: Aphids, Myzus persicae
4. Cucurbitacin: Cucurbit fruit flies
5. Salicylic acid: Rice stem borer

Physical factors in antibiosis Thick cuticle, glandular hairs, silica deposits, tight leaf sheath, etc.

c. Tolerance Ability to grow and yield despite pest attack. It is generally attributable to plant vigour, regrowth of damaged tissue, to produce additional branches, compensation by growth of neighbouring plants.

Use of tolerance in IPM - Tolerant varieties have high ETL - require less insecticide - Apply less selection pressure on pests. Biotype development is less

HPR in IPM - HPR is a very important component of IPM - Selection and growing of a resistant variety minimise cost on all other pest management activities Compatibility of HPR in IPM

a. Compatability with chemical control - HPR enhances efficacy of insecticides - Higher mortality of leaf hoppers and plant hoppers in resistant variety compared to susceptible variety - Lower concentration of insecticide is sufficient to control insects on resistant variety

b. Compatibility with biological control - Resistant varieties reduce pest numbers - thus shifting pest: Predatory (or parasitoid) ratio favourable for biological control. e.g. Predatory activity of mirid bug Cyrtorhinus lividipennis on BPH was more on a resistant rice variety IR 36 than susceptible variety IR 8 - Insects feeding on resistant varieties are more susceptible to virus disease (NPV)

c. Compatibility with cultural method - Cultural practices can help in better utilization of resistant varieties. e.g. Use of short duration, pest resistant plants effective against cotton boll weevil in USA.

Advantages of HPR as a component in IPMSpecificity: Specific to the target pest. Natural enemies unaffected Cumulative effect: Lasts for many successive generations Eco-friendly: No pollution. No effect on man and animals Easily adoptable: High yielding insect resistant variety easily accepted and adopted by farmers. Less cost. Effectiveness: Res. variety increases efficacy of insecticides and natural enemies Compatability: HPR can be combined with all other components of IPM Decreased pesticide application: Resistant varieties requires less frequent and low doses of insecticides Persistence: Some varieties have durable resistance for long periods Unique situations: HPR effective where other control measures are less effective e.g. a. When timing of application is critical b.Crop of low economic value c. Pest is continuously present and is a single limiting factor

Disadvantages of HPR Time consuming: Requires from 3-10 years by traditional breeding programmes to develop a res. variety. Biotype development: A biotype is a new population capable of damaging and surviving on plants previously resistant to other population of same species. Genetic limiation: Absence of resistance genes among available germination

LEGAL CONTROL METHODS - DEFINITION - PEST INTRODUCTIONS- QUARANTINE - PHYTOSANITARY

Definition: Preventing the entry and establishment of foreign plant and animal pest in a country or area and eradication or suppression of the pests established in a limited area through compulsory legislation or enactment

Pests Accidentally Introduced Into India

1. Pink bollworm - *Pectinophora gossypiella* 2. Cotton cushion scale - *Icerya purchasi* 3. Wooly aphid of apple - *Aphelinus mali* 4. SanJose scale - *Quadraspidiotus perniciosus* 5. Potato tuber moth - *Gnorimoschima operculella* 6.Cyst (Golden) nematode of potato - *Globodera* sp. 7. Giant african snail - *Acatina fullica* 8. Subabul psyllid - *Heteropsylla cubana* 9.Bunchytop disease of banana 10. Spinalling whitefly - *Aleyrodicus dispersus*

Foreign Pests From Which India Is Free Mediterranean fruitfly - *Ceratitis capitataGrapeavine phylloxera* Cotton boll weevil - *Anthonomos grandis* Codling moth of apple - *Lasperysia pomonella*

Quarantine

Isolation to prevent spreading of infection

Plant Quarantine

Legal restriction of movement of plant materials between countries and between states within the country to prevent or limit introduction and spread of pests and diseases in areas where they do not exist.

PEST LEGISLATIONS

1905 - 'Federal Insect Pest Act' - first Quarantine act against SanJose scale

1912 - 'US Plant Quarantine Act'

1914 - 'Destructive Insects and Pests Act' of India (DIPA)

1919 - 'Madras Agricultural Pests and Diseases Act'

1968 - 'The Insecticides Act'

DIFFERENT CLASSES OF QUARANTINE

Foreign Quarantine (Legislation to prevent the introduction of new pests, diseases and weeds from foreign countries)

Plant quarantine inspection and treatments at sea ports of Mumbai, Kolkata, Cochin, Chennai and Visakapattinam and airports of Amritsar, Mumbai, Kolkata, Chennai and New Delhi Import by post parcel prohibited except by scientists Import of plant materials prohibited or restricted Import permits required for importation of plant material Phytosanitary certificate from the country of origin is required

Phytosanitary certificate is issued by State Entomologist and Pathologists to the effect that the plant or seed material is free from any pest or disease

a. Fumigation of imported plant material based on need

b. Taking care of pests of quarantine concern in India

Restriction imposed on the importation of

i. Sugarcane setts - to prevent West Indies sugar weevil

ii. Coffee seeds - to prevent coffee berry borer

iii.Cotton seeds - to prevent cotton boll weevil

a. Export of pepper, cardamom and tamarind restricted

b. In 1946, Directorate of Plant Protection, Quarantine and Storage, Government of India established - for inspection of export and import of agricultural commodities.

2. Domestic quarantine (within different parts of country) - Flutted scale Icerya puchasi noticed in Nilgiris and Kodaikanal in 1943 in Wattle trees. Quarantine stations at Mettupalayam and Gudalur for Nilgiris and Shenbaganur for Kodaikanal to prevent spread of flutted scale in TN. - Preventing movement of Banana from Palani hills to prevent Bunchy top spread

3. Legislation to take up effective measures to prevent spread of established pests Example: Cotton stem weevil, Groundnut RHC, Coffee stem borer, Coconut black headed caterpillar (BHC), Sugarcane top borer.

i. Stem weevil of cotton (Combodia cotton, 1913) Previous crop to be removed before Aug.1 Next crop to be sown not before Sep. 1 to keep land free of cotton for sometime

ii. RHC of groundnut (1930) - Collection of pupae in summer ploughing - Putting light traps and bonfires - Hand picking of egg and larvae - Spread leaves in field, trench, collect and destroy

iii. Stem borer of coffee (1946) This act is still in force in Salem, Coimbatore, Madurai and Nilgiris - All infested plants to be removed and destroyed by 15th December every year - Swabbing with wettable powder (Carbaryl) on stem and branch Legislation to prevent the adulteration and misbranding of insecticides and to determine the permissible residues in food stuff. Legislation to regulate the activities of men engaged in pest control

THE INSECTICIDES ACT, 1968

- Implemented in 1971 (Insecticides Rule, 1971)
- Safety oriented legislation
- Regulates import, manufacture, storage, transport, sale, distribution and use of insecticides with a view to prevent risk to human beings and animals
- Regulatory provision

- Compulsory registration, licensing, inspection, drawal and analysis of samples, detention, seizure and confiscation of stocks, suspension and cancellation of licences, etc.

- Enforcement of the act is joint responsibility of central and state governments.

- Statutory bodies

- (i) Central Insecticides Board (CIB) (28 members) Chairman (CIB) - Director General of Health Services (ii) Registration Committee (RC) (5 members) Chairman (RC) - Deputy Director General, Crop Sciences, ICAR

Salient features of the insecticides act (1968)

- Compulsory registration with CIB (Central level)

- Licence for manufacture, formulation and sale at state level

-Inter departmental/Ministerial/Organisational co-ordination achieved by high level Advisory Board "Central Insecticides Board" with 28 members form various fields - RC to lookafter registration aspects of insecticides - Enforcement by Insecticide inspectors at state/central level - Power to prohibit the import, manufacture and sale of insecticides and also confiscate stocks. Guilty are punishable.

Role of Plant Quarantine in the Export of Agricultural Commodities

International Plant Protection Convention (1951) of FAO, UN. Article V of the convention makes it mandatory for member countries to issue Phytosanitory certificate (PSC) PSC should be conformity with Plant Quarantine Regulations of importing country. Agricultural commodities during export should be accompanied by PSC.

General requirement of PSC

- Inspected agrl. commodities should be free from pest/diseases - Takes time for inspection - seek prior guidance from plant quarantine authorities in India

Special requirements of PSC

- Additional declarations required from importing country for freedom of commodities from specific pests/diseases - Obtain complete details of requirements of importing country

Technical limitations

- Rules not relaxable. No compromise with principles of Plant Quarantine.

Procedure for getting PSC

- Application to be submitted to Plant Quarantine and Fumigation station - Will be scrutinised, samples drawn and examined for pest, diseases, weeds - If free PSC issued - If found infested - rejected, PSC not issued - Sometimes treatment (fumigation) given and PSC issued

Authority to issue PSC

Union Govt. of Agrl.has authorised officers in Central and State Govt. and UT PPA to Govt. of India - Heads of Unit

MECHANICAL CONTROL

Use of mechanical devices or manual forces for destruction or exclusion of pests.

A. Mechanical destruction: Life stages are killed by manual (or) mechanical force. Manual Force

1. Hand picking the caterpillars
2. Beating: Swatting housefly and mosquito
3. Sieving and winnowing: Red flour beetle (sieving) rice weevil (winnowing)
4. Shaking the plants: Passing rope across rice field to dislodge caseworm and shaking neem tree to dislodge June beetles
5. Hooking: Iron hook is used against adult rhinoceros beetle
6. Crushing: Bed bugs and lice
7. Combing: Delousing method for Head louse
8. Brushing: Woolen fabrics for clothes moth, carper beetle.

Mechanical force

1. **Entoletter:** Centrifugal force - breaks infested kernels - kill insect stages - whole grains unaffected - storage pests.
2. **Hopper dozer:** Kill nymphs of locusts by hording into trenches and filled with soil.
3. **Tillage implements:** Soil borne insects, red hairy caterpillar.
4. **Mechnical traps:** Rat traps of various shapes like box trap, back break trap, wonder trap, Tanjore bow trap.

B. Mechanical exclusion

Mechanical barriers prevent access of pests to hosts.

1. Wrapping the fruits: Covering with polythene bag against pomegrante fruit borer.
2. Banding: Banding with grease or polythene sheets - Mango mealybug.
3. Netting: Mosquitoes, vector control in green house.
4. Trenching: Trapping marching larvae of red hairy catepiller.
5. Sand barrier: Protecting stored grains with a layer of sand on the top.
6. Water barrier: Ant pans for ant control.
7. Tin barrier: Coconut trees protected with tin band to prevent rat damage.
8. Electric fencing: Low voltage electric fences against rats.

Advantage of mechanical control

1. Home labour utilization

2. Low equipment cost
3. Ecologically safe
4. High technical skill not required in adopting.

Disadvantages:

1. Limited application
2. Rarely highly effective
3. Labour intensive

PHYSICAL METHODS

This envisages use of certain physical forces for eradication of insects. Several types of traps attract the insects and these traps provide valuable information on the insect population fluctuations and their peak period of emergence as well as their activities. Traps are also useful in mass trapping and killing of insects. The traps based on the physical factors are light and sticky traps.

Chemical factors - pheromones and bait traps

Mechanical factors - suction, pitfall and emergence traps

Light traps: The first known record of attraction of some adult insects to artificial light was observed and recorded by the Greek Poet Aeschylus (525 - 456 BC). In earlier days bone fires were used for attracting and killing insects. This was followed by kerosene burning lamps and lanterns as source of attractants. In a number of cases, these lamps or lanterns were used inside a room or other sheltered location where the attracted moths were trapped and caught by hand. Later with the scientific advancements, the light traps of various models were designed, developed and tested for several insects.

Sources of light

Numerous lamps were used in traps to determine the photo responses of various economically important insects during the past 25 years. These lamps provide a wide range of radiation output in terms of quality (wavelength) and quantity (power). These lamps can be categorized into three major groups viz.,

1. Inside frosted incandescent lamp
2. Mercury vapour lamp and
3. Black light

Incandescent lamps produce small amount of UV, considerable visible light especially rich in yellow and red and as peak reduction in the infrared region. Mercury vapour lamps produce primarily UV, blue and green radiation with little red. Black light is a popular name for UV radiant energy with the range of wavelengths from 320 to 380 nm.

Incandescent light traps are used for trapping Cutworms Agrotis orthogonia, Rice gall midge, BPH, WBPH, leafhoppers and biting midges

Mercury light traps - attract insects belonging to the family pyralidae, sphingidae, Plusia spp., Spodoptera spp., noctuidae.

Black light trap - used for trapping a wide variety of nocturnal insects e.g. Heliothis zea, European corn borer.

Use of light traps

1. Light traps are useful in studying the seasonal incidence of insect pests and evolving forecasting models.
2. Light traps can be employed to survey the occurrence, distribution, abundance and flight pattern of various insect pests in a given locality.
3. Light traps give an indication about brood emergence of insect pests for taking up appropriate control measures.
4. From light trap catches migration of certain insect species can be worked out.

Sticky traps:

Sticky traps are generally used for catching the aerial insect population. Generally smaller size insects like leafhoppers, while flies, aphids are trapped in these models. The sticky materials used include castor oil, vaseline, tangle food, etc., The sticky trap models include simple rectangular galvanized sheets, plastic jars or tin boxes, cylindrical tubes etc., over which the sticky adhesive material is applied. Generally different colours are painted on the trap depending upon the preference by various insects to colours and used as coloured sticky traps.

Use of activated clay:

Kaolinite clay after successive activation with aid and heat can be mixed with showed grains. The clay minerals absorb the lipoid layer over the insect cuticle, and the insect lose their body mixture and die of desiccation 1 kg mixed in 100 kg of grains. Drie-die-USA-highly porous finally divided silica gel when applied abrade insect cuticle and cause loss of mixture used against stored product insects, grasshoppers, mites, phirid flies, wasps and thrips.

Artificial heating or cooling of stored products

Simple heat or cold may be sufficient to kill insects of stored products. Use of heat and cold is most appropriate around the home. A temperature of +600C for 1 hr or 200C for four days is usually sufficient to kill grain pests. Grain storage facilities in the upper midwinter United States, Canana and the Soviet Union can harness midwinter air to reduce infestations. Dielectric heating with micro waves killed mango nut weevils. When half ripe fruits were exposed to microwave in a duration of 10-15 seconds in 4-5 increments, 50, 95 and 99 per

cent mortality of weevil in the store was obtained at 510C, 660C and 740C. However, partial cooking of pulp in small areas is noticed.

Manipulation of water and humidity

Dehydration or reducing mixture below certain level.Eg. Less than 10 per cent moisture controls coffee berry bean in storage. Cotton seeds are sun dried to kill the hibernating pink bollworm larvae.

CULTURAL PRACTICES IN PEST MANAGEMENT

Over thousands of years our forefathers have shared their crops with pests. They learned, through trial and error, the best crops to grow, the best sowing times and the best crop combinations and spacing that would reduce the insect pest's share of the harvest. They selected seeds and plants that were tolerant to the pests in the fields. Any farmers who did not know the good farming practices did not survive. The diversity of a cropping system can be increased by intercropping, trap cropping presence of weeds or by crops grown in the adjacent fields. When inter planted crops or weeds in the crop are also suitable host plants for a particular pest, they may reduce feeding damage to the main crop by diverting the pest. On the other hand, these may also serve as an essential source of food or shelter at some point in the life cycle or during some part of the season, enabling the pest to maintain or build up its numbers in the field and so attack the main crop more severely.

Cropping systems like inter cropping, or mixed cropping, alley cropping, strip cropping, etc., when carefully selected can reduce pest incidence by

i. Acting as a barrier, a hazard or camouflage

ii. Acting as alternate hosts, diverting the pest away from the crop at risk.

iii. Benefiting the natural enemies of pest or minimizing the risks involved in monocultures. Raising lab lab, cowpea or other short statured pulses as a mixed crop with sorghum minimizes infestation by stem borer.

Intercropping contributes

i. To the diversity of agro ecosystem

ii. Change in the microclimate and

iii. Influences on the build up of population of insect pests.

-Pest outbreaks are less in mixed strands due to crop diversity than in sole strands.

-Regulation of pests in intercropping systems is due to

1. Physical means (Protection from wind, hiding, shading, alteration of colour or shape of the stand etc.,)

2. Biological interference - production of adverse chemical stimuli, presence of predators, parasitoids etc.,

Trap cropping: Plant strands that are grown to attract insects or other organisms like nematodes to protect target crops from pest attack.

Protection is achieved

1. By either preventing the pests from reaching the crop or

2. By concentrating them in a certain part of the field where they can economically be destroyed.

3. Manipulations of the preferred plant strands in time and space would attract the insects and lead to the concentration of the pests at the desired site. i.e. trap crop. Eg. DBM - main crop- cabbage

Trap crop - mustard 25:2 rows

Spodoptera litura - Chillies - main trap

Castor- border crop

Crop rotation: Growing of crops which are hosts for an insect pest in a successive manner will provide a continuous supply of food and uninterrupted breeding facilities and this will result in increase of population of the pest. Bhendi following a cotton crop will suffer from increased pest infestation because most of the pests of cotton are also so of bhendi. If corn and soybeans are rotated on a two year cycle, large populations of corn root worms, white grubs and wire worms are prevented from developing, though some of the generalist pests such as seed corn maggot and cutworms are unaffected.

Seeds and manipulation of sowing dates Changes in sowing and planting dates can help in the avoidance of egg laying period by certain pests, the establishment of tolerant plants before pest occurrence, the maturation of crop before abundance of pest, the synchronization of pests with natural enemies. Pest free planting materials should be used. Early sowing, increased seed rate (12.5 kg/ha) - effective against sorghum shoot fly.

Tillage operations Summer ploughing is a specific tillage operation aimed at destruction of over wintering insects. eg. RHC in groundnut. Ploughing and hoeing help to bury the stages of insects or expose shapes of soil inhabiting insects to be picked up by birds. Trimming and plastering of field bunds in rice fields expose eggs of grasshoppers and eliminate the bugs breeding in grasses. In temperate climates, autumn ploughing and disking exposes over wintered forms of many insects to predation, freezing and so on. In mid western USA, the European crop borer over winter as matured larva. Corn stalks left in the field after harvest. Plouging of stubble exposes these larvae and results in more than 90% mortality.

Another eg.Hessian fly in North America. The pest has a very short life span (34 days) and oviposition occurs over a limited span of time during early autumn. Damage to winter wheat can be avoided entirely by planting after the so called fly free date in autumn. This is most

effective when all the growers in a region co-operate. Similarly early planted peanuts avoid aphid damage in tropical Africa.

Other cultural practices

1. Full sanitation in the field including removal of alternate hosts, crop residues will helps in raising a healthy crop.

2. In rice ecosystem, alternate wetting and drying minimize BPH population and prevented the dispersal of BPH between fields.

3. De-trashing in sugarcane on 150th day to reduce mealy bug and internode borer incidence.

4. Pruning of dried twigs or branches to eliminate pests like orange borer and scale insects.

5. Wider spacing, split application of N fertilizer reduces BPH.

6. In Florida, fallow land is flooded prior to the production of winter vegetables. Of approximately 30,000 ha, about 20 per cent is flooded annually to suppress soil pests and to conserve and stabilize organic soils in the region. Primary targets of pest management in this operation are immature wire worms which attack germinating plants and underground plant parts. To be effective against this pest, production areas are flooded for six weeks or more.

In another instance, sprinkler irrigation has been effective in suppressing certain foliage feeding insects.

The potato tuber moths, *Phthorimaea operculella* is effectively suppressed by frequent overhead irrigation of potatoes in New Zealand. The moist conditions appear to deter egg laying and cause mortality of newly eclosed larvae before they tunnel into the plants. Another pest managed by sprinkler irrigation is the DBM, on watercress in Hawaii and head cabbage in Indiana. Here intermittent applications of water are made during early evening hours, which are believed to disrupt moth mating and egg laying.

BIOLOGICAL CONTROL - DEFINITION - HISTORY AND DEVELOPMENT - CLASSICAL EXAMPLES

Biological control Definition The study and utilization of parasitoids, predators and pathogens for the regulation of pest population densities.

Biological control can also be defined as the utilization of natural enemies to reduce the damage caused by noxious organisms to tolerable levels.

Biological control is often shortened to biocontrol.

History and development of biological control and classical examples of biological control

Ancient times - In China Pharoah's ant Monomorium pharaonis was used to control stored grain pest. Red ant Oecophylla spp. used to control foliage feeding caterpillar.

Year 1762 - 'Mynah' bird imported from India to Mauritius to control locust.

1770 - Bamboo runways between citrus trees for ants to control caterpillars.

1888 - First well planned and successful biological control attempt made

- During 1888 citrus industry in California (USA) seriously threatened by cottony cushion scale, *Icerya purchasi*
- Chemical treatments not known at that time
- Mr. C.V. Riley, a prominent entomologist suggested that the scale inset originated from Australia and natural enemy for the scale from Australia should be introduced into USA
- Mr. Albert Koebele was sent to Australia
- He found a beetle called Vedalia (*Rodolia cardinalis*) attacking and feeding on seeds
- Vedalia beetle (*Rodolia cardinalis*) was imported in November 1888 into USA and allowed on scale infested trees
- Within a year spectacular control of scale insect achieved
- Even till date this beetle controls the scale insect
- After this successful attempt of biological control many such introduction of natural enemies were tried.

1898 - First introduction of natural enemy into India

1898 - A coccinellid beetle, *Cryptolaemus montrouzieri* was imported into India from Australia and released against coffee green scale, *Cocus viridis*. Even today it is effective against mealybugs in South India.

1920 - A parasitoid *Aphelinus mali* introduced from England into India to control Woolly aphid on Apple, *Eriosoma lanigerum*.

1929-31 - *Rodolia cardinalis* imported into India (from USA) to control cottony cushion scale *Icerya purchasi* on Wattle trees.

1958-60 - Parasitoid*Prospatella perniciosus* imported from China

1960 - Parasitoid *Aphytis diaspidis* imported from USA Both parasitoids used to control Apple Sanjose scale *Quadraspidiotus perniciosus*

1964 - Egg parasitoid *Telenomus* sp. imported from New Guinea to control Castor semilooper *Achaea janata*

1965 - Predator *Platymeris laevicollis* introduced from Zanzibar to control coconut Rhinoceros beetle, *Oryctes rhinoceros*

History, development, classical examples of biocontrol

Till 1988 At global level 384 importations made against 416 species of insect pests. Out of them

164 species (39.4%) - Completely controlled

75 species - Substantially controlled

15 species - Partially controlled

- Regional Station of Commonwealth Institute of Biological Control (CIBC) established at Bangalore in 1957
- Presently Project Directorate of Biological Control (PDBC) Bangalore looks after Biocontrol in India.

Factors affecting biological control

1. Tolerance limit of crop to insect injury - Successful in crops with high tolerance limit
2. Crop value - Successful in crops with high economic value
3. Crop duration - Long duration crops highly suitable
4. Indigenous or Exotic pest - Imported NE more effective against introduced pest
5. If alternate host available for NE, control of target pest is less
6. If unfavourable season occurs, reintroduction of NE required
7. Presence of hyperparasites reduces effectiveness of biocontrol
8. Tritrophic interaction of Plant-Pest-Natural enemy affects success of biocontrol, e.g. *Helicoverpa* parasitization by *Trichogramma* more in timato than corn
9. Use of pesticides affects natural enemies
10. Selective insecticides (less toxic to NE required)
11. Identical situation for successful control does not occur

Qualities of an effective natural enemy

1. Adaptable to the environmental condition
2. Host specific (or narrow host range)

3. Multiply faster than the host (with high fecundity)
4. Short life cycle and high female: male ratio
5. High host searching capacity
6. Amenable for easy culturing in laboratory
7. Dispersal capacity
8. Free from hyper parasites
9. Synchronise life cycle with host

Three major techniques of biological control

1. Conservation and encouragement of indigenous NE Defined as actions that preserve and increase NE by environmental manipulation. e.g. Use of selective insecticides, provide alternate host and refugia for NE.

2. Importation or Introduction Importing or introducing NE into a new locality (mainly to control introduced pests).

3. Augmentation Propagation (mass culturing) and release of NE to increase its population. Two types, (i) Inoculative release: Control expected from the progeny and subsequent generations only. (ii) Inundative release: NE mass cultured and released to suppress pest directly e.g. *Trichogramma* sp. egg parasitoid, *Chrysoperlacarnia* predator

ROLE OF PARASITOIDS AND PREDATORS IN IPM

- Parasitoids and predators may be used in Agriculture and IPM in three ways.

They are

i) Conservation ii) Introduction iii) Augmentation - (a) Inoculative release, (b) Inundative release

- Since biological control is safe to environment, it should be adopted as an important component of IPM.
- Biological control method can be integrated well with other methods namely cultural, chemical methods and host plant resistance (except use of broad spectrum insecticides)
- Biological control is self propagating and self perpetuating
- Pest resistance to NE is not known
- No harmful effects on humans, livestock and other organisms
- Biological control is virtually permanent
- Biological agents search and kills the target pest

MICROBIAL CONTROL

- It is a branch of biological control
- Defined as control of pests by use of microorganisms like viruses, bacteria, protozoa, fungi, rickettsia and nematodes.

I. VIRUSES

Viruses coming under family Baculoviridae cause disease in lepidoptera larvae. Two types of viruses are common. NPV (Nucleopolyhedro virus)e.g. HaNPV, SlNPV GV (Granulovirus) e.g. CiGV

Symptoms

Lepidopteran larva become sluggish, pinkish in colour, lose appetite, body becomes fragile and rupture to release polyhedra (virus occlusion bodies). Dead larva hang from top of plant with prolegs attached (Tree top disease or "Wipfelkrankeit")

II. BACTERIA

Spore forming (Facultative - Crystalliferous) 2 types of bacteria Spore forming (Obligate) Non spore forming

i. Spore forming (Facultative, Crystelliferous) The produce spores and also toxin (endotoxin). The endotoxin paralyses gut when ingested e.g. *Bacillus thuringiensis* effective against lepidopteran. Commercial products - Delfin, Dipel, Thuricide

ii. Spore-forming (Obligate) e.g. *Bacillus popilliae* attacking beetles, produce 'milky disease' Commercial product - 'Doom' against 'white grubs'

iii. Non-spore forming e.g. *Serratia entomophila* on grubs

III. FUNGI

i. Green muscardine fungus - *Metarhizium anisopliae* attack coconut rhinoceros beetle

ii. White muscardine fungus - *Beaveria bassiana* against lepidopteran larvae

iii. White halo fungus - *Verticillium lecanii* on coffee green scale.

Other Microbs: Protoza, Nematodes

Limitations of biocontrol technique

- Complete control not achieved
- Slow process
- Subsequent pesticide use restricted
- Expensive to culture many NE
- Requires trained man power

CHEMICAL CONTROL - DEFINITION - HISTORY AND DEVELOPMENT

Chemical Control:

Management of insect pests using chemical pesticides is termed as chemical control.

Pesticides: Chemicals which are used to kill pests

History of insecticide development

Year Chemicals

900 - Arsenites in China (Inorganic compound)

1690 - Tobacco used in Europe (Plant/natural product)

1787 - Soaps used in Europe

1867 - Paris Green in US

1874 - DDT synthezized by Zeidler

1883 - Bordeau in France

1925 - Dinitro compounds (First synthetic organic insecticide)

1932 - Thiocyanates

1939 - DDT insecticidal property discovered by Paul Muller of Switzerland. Paul Muller awarded Nobel Prize in 1948 for discovering insecticidal property of DDT

1941 - BHC in France and UK (in 1942) (BHC is presently called as HCH)

1944 - Parathion (Organo phosphate) discovered by Gerhard Schrader in Germany

1945 - Chlordane (Cyclodian compound) in Germany

1947 - Carbamate insecticides in Switzerland

1962 - Rachel Carson's Silent Spring appears (US) (This is not a chemical. The book ' Silent Spring' created awareness about ill effects of pesticides)

1967 - First JH mimic (Juvenile Hormone mimic) used in US (Insect growth regulator)

1970 - Development of synthetic pyrethroids (UK) (Fast degradation) (Effective at very low doses)

1980 - Discovery of avermectins (derived from bacteria). Effective at low dose.Fast degradation.

1990 - Discovery of newer groups like (1) Neonicotinoids (Imidacloprid), similar to natural nicotin, (2) Spinosyns (e.g. Spinosad) derived from actinomycet

TOXICITY PARAMETERS

Toxicity of a given chemical to an organism can be measured using various parameters as listed below.

1) LD50 or Median lethal dose

LD50 is defined as the amount of insecticide per unit weight which will kill 505 of the particular organism or insect. LD50 usually expressed as mg/kg body weight or g/larva or adult insect.

2) LC50 or Median lethal concentration

Defined as the concentration of insecticide required to kill 50% of the given organism or insect. This is used when the exact dose per insect is not known, but the concentration is known. LC50 is expressed in PPM (1/1,000,000) or Percentage (1/100)

3) LT50 (Median lethal time)

LT50 is defined as the time required to kill 50% of the population at a certain dose or concentration. LT50 expressed in hours or minutes. LT50 is used in field studies and also for testing insect viruses (NPV).

4. KD50: Median knockdown dose: Dose of insecticide or time required to
5. KT50: Median knockdown time: knockdown 50% of the insects

KD50 and KT50 are used for evaluating synthetic pyrethroids against insects.

6. ED50: Median effective dose: These terms are used to express the
7. EC50: Median effective concentration: effectiveness of insect growth regulators (IGR)

ED50 and EC50 are defined as the dose or concentration of the chemical (IGR) required to affect 50% of population and produce desired symptoms in them.

Toxicity terms used to express the effect on mammals

1. Acute toxicity: Toxic effect produced by a single dose of a toxicant
2. Chronic toxicity: Toxic effects produced by the accumulation of small amounts of the toxicant over a long period of time
3. Oral toxicity: Toxic effect produced by consumption of pesticide orally
4. Dermal toxicity: Toxic effect produced when insecticide enters through skin
5. Inhalation toxicity: Toxic effect produced when poisonous fumes of insecticide are inhaled (fumigants)

Other terms: Acute oral, acute dermal, acute inhalation toxicity, etc.

Ideal Qualitiesof an Insecticide

An ideal insecticide should posses the following qualities

Kill the target insect effectively and quickly

Be less toxic to natural enemies

Be less toxic to honey bees, soil microorganisms

Be less toxic to fishes and mammals

Less hazardous and less toxic during handling or accidental consumption by human beings
Quickly degradable in environment and should be less persistent (Residues should be very less)
Should not cause resurgence of the target insect (i.e. Increase in population of target insect) e.g. Chlorpyriphos causes resurgence of BPH on rice.
Should not cause outbreak of secondary pest on a minor pest by killing the natural enemies
should have a complex mode of action against which resistance development will take more time. e.g. Azadirachtin from neem tree has complex action
Should have a longer storage life or shelf life
It is advantageous to select an insecticide which can kill a relatively broad spectrum of target pests
It should be cost effective (High benefit/Cost ratio) and safe to use (High benefit/Risk ratio)

PESTICIDES GROUPS

Groups of pesticides : The pesticides are generally classified into various groups based on pest organism against which the compounds are used, their chemical nature, mode of entry and mode of action.

1. Based on organisms

a) Insecticides : Chemicals used to kill or control insects (eg.) malathion

b) Rodenticides: Chemicals exclusively used to control rats (eg.) Zinc phosphide

c) Acaricides : Chemicals used to control mites on crops / animals (eg.) Dicofol

d) Avicides : Chemicals used to repel the birds (eg.) Anthraquionone

e) Molluscicides: Chemicals used to kill the snails and slugs (eg.) Metaldehyde

f) Nematicides: Chemicals used to control nematodes (eg.) Ethylene dibromide

g) Fungicide: Chemicals used to control plant diseases caused by fungi (eg.) Copper oxy cholirde

h) Bacteric: Chemicals used to control the plant diseases caused by bacteria (eg.) Streptomycin sulphate

i) Herbicid: Chemicals used to control weeds (eg.) 2,4, - D

2. Based on mode of entry

a) Stomach poison: The insecticide applied in the leaves and other parts of the plant when ingested, act in the digestive system of the insect and bring about kill (eg.) Malathion.

b) Contact Poison: The toxicant which brings about death of the pest species by means of contact (eg.) Fenvalerate.

c) Fumigant: Toxicant enter in vapour form into the tracheal system (respiratory poison) through spiracles (eg.) Aluminium phosphide

d) Systemic poison: Chemicals when applied to plant or soil are absorbed by foliage (or) roots and translocated through vascular system and cause death of insect feeding on plant. (eg.) Dimethoate.

3. Based on mode of action

a) Physical poison : Toxicant which brings about kill of one insect by exerting a physical effect (eg.) Activated clay.

b) Protoplasmic poison : Toxicant responsible for precipitation of protein (eg.) Arsenicals.

c) Respiratory poison : Chemicals which inactivate respiratory enzymes (eg.) hydrogen cyanide.

d) Nerve poison : Chemicals inhibit impulse conduction (eg.) Malathion. e) Chitin inhibition : Chemicals inhibit chitin synthesis (eg.) Diflubenzuron.

4. Based on chemical nature Classification based on chemical nature of insecticides

Pesticides

Inorganic Pesticides   Organic pesticides

Petroleum   Animal Oils   origin   Plant origin   Synthetic organic insecticides

Organochlorine group   Organophosphate pyrethroid   Cyclodiene   Synthetic group   Carbamate aneous   Miscell groups

i. **Inorganic pesticides Inorganic chemicals used as insecticides**

Eg. Arsenic, Fluorine, Sulphur, lime sulphur (Insecticides) zinc phosphide (Rodenticide)

ii. **Organic pesticides Organic compounds (constituted by C, H, O and N mainly)** Hydrocarbon oil (or) Petroleum oil – eg. Coal tar oil, kerosine etc., Animal origin insecticides – eg. Nereistoxin extracted from marine annelids – commercially available as cartap, padan.

Plant origin insecticides : Nicotine from tobacco plants, pyrethrum from Chrysanthemum flowers, Rotenoids from roots of Derris and Lonchocarpus Neem – azadirachtin, Pongamia glabra, Garlic etc.,

Synthetic organic compounds: These organic chemicals are synthetically produced in laboratory.

i. Chlorinated hydrocarbon (or) organochlorines Eg. DDT, HCH, Endosulfan, Lindane, Dicofol (DDT, HCH banned)

ii. Cyclodienes Eg. Chlordane, Heptachlor (Banned chemicals)

iii.Organophosphates : (Esters of phosphoric acid) .

Eg. Dichlorvos, Monocrotophos, Phospamidon, Methyl parathion, Fenthion, Dimethoate, Malathion, Acephate, Chlorpyriphos

iv. Carbamates: (Derivatives of carbamic acid) Eg. Carbaryl, Carbofuran, Carbosulfan

v. Synthetic pyrethroids: (Synthetic analogues of pyrethrum) Eg. Allethrin, Cypermethrin, Fenvalerate

vi. Miscellaneous compounds Neonicotinoids (Analogues of nicotine) eg. Imidacloprid Spinosyns (Isolated from actinomycetes) eg. Spinosad Avermectins (Isolated from bacteria) eg. Avermectin, Vertimec Fumigants : Eg. Aluminium phosphide, Hydrogen cyanide, EDCT

STUDY OF IMPORTANT INSECTICIDES

Botanical insecticides

Nicotine from tobacco plants,

pyrethrum from Chrysanthemum flowers,

Rotenoids from roots of Derris and Lonchocarpus

Neem – azadirachtin,

Pongamia glabra, Garlic etc.,

Neem based Insecticides: Achook, NeemAzal, Neemark, Neemgold, Neemguard, Neemrich, Nimbbecidine, wellgro

Cyclodienes Eg. Aldrin, Dieldrin, BHC, Chlordane, Heptachlor (Banned chemicals), Endosulphan.

Organophosphates : (Esters of phosphoric acid) .

Eg. Dichlorvos, Monocrotophos, Phospamidon, Methyl parathion, Fenthion, Dimethoate, Malathion, Acephate, Chlorpyriphos

Carbamates: (Derivatives of carbamic acid) Eg. Carbaryl, Carbofuran, Carbosulfan

Synthetic pyrethroids: (Synthetic analogues of pyrethrum) Eg. Allethrin, Cypermethrin, Fenvalerate

***Chapter XII*:NOVEL INSECTICIDES**

A number of novel insecticides with unique modes of action were registered during the late 1990s and early 2000s for insect control in agriculture. These new insecticides have several advantages over older classes of insecticides. Low mammalian toxicity allows for short re-entry and pre harvest intervals, allowing the insecticides to be easily incorporated into pest control programmes. Many also have greater selectivity and so are less likely to harm natural enemies than the broad spectrum insecticides. The new insecticides also have some disadvantages because of their narrower range of activity, each insecticide generally controls only one pest group within a group.

Nicotinyl Insecticides					
Insecticide	**Mode of Action**	**Toxicity**	**Dosage**	**Formulation**	**Effectiveness**
Imidacloprid	Contact & Systemic and similar to nicotine. Affect ACh receptors at C & P nervous system.	Low mammalian toxicity	10-300 g/ha	SL(Soluble Liquid)	With excellent systemic and good residual characteristics; it is appropriate for seed treatment and soil application, used on cotton, maize, rice, vegetables, sorghum, potato & foliar spray.
Thiomethoxam	Contact, stomach & systemic, rapidly taken into plant system. Affect synapses of CNS	”	10-200 g/ha	EC & WS	Seed treatment & foliar for maize. Sorghum, sugar-beet, oilseed, cotton, peas, beans, sunflower, rice, potato
Acetamiprid	”	”	75-300 g/ha	EC	Soil & foliar application. Aphids, Thysanopteran, Lepidopteran

Macrocyclic lactone insecticides

Avermectins	Contact, systemic, do not exhibit knock down effect; blocks chloride ions into nerve cells resulting in loss of cell function & disruption of nerve impulse	”	”	SL	Antihelmenthic, acaricidal and insecticidal-lepidopterans
Thiourea derivatives					
Emamectin (It is second generation avermectin analog)	Contact, Stop feeding, paralysis & die in 3-4 days	Toxic to natural enemies	”	SL	Lepidopterans
Ivermectin	”	”	”	SL	Antiparasitic, worms, mites, lice
Spinosyn Insecticides					
Spinosad (produced by *Sacchropolyspora spinosa* through fermentation technique)	Systemic	Low mammalian toxicity	75-100 g/ha	SC	*H. armigera*, leaf hopper, aphids, whitefly on cotton
Oxidiazine					
Indoxacarb	Systemic Blocks the sodium channel in nerve cells causing paralysis & death within 2 to 5 days	”	75-100 g/ha	SC	Lepidopteran larvae and certain species of sucking insects such as Lygus bugs.
Pyrroles					
Pirate	Contact, systemic	Moderately toxic to mammals	”	EC, SC	Acaricidal, Coloptera, Diptera, Hemiptera, Lepidoptera
Phenylpyrazoles					
Fipronil	Contact, Systemic, Stomach It is potent blocker of GABA (Gamma amino butyric acid)gates chloride channel	”	”	SC	Soil & foliar insect pests

Sulfathiourea, Noxytiolin, Burimamide It is similar to urea, except oxygen atom is replaced by a sulphur atom. Banned	Systemic, Contact Carcinogen, Goitrogenic Hepatic tumors, Bone marrow depression		100-200 g/ha	EC, SC	Lepidoptera, Coleoptera, Sucking pests.
Pyridine Azomethines					
Pymetrozine	Systemic	Low toxic	”	EC	Sucking pests, aphids, whitefly
Flonicamid	”	”	”	EC, SL	Lepidopterans, Coleopterans

Pheromones

Pheromones are chemicals secreted into the external environment by an animal which elicit specific reaction in a receiving individual of the same species. They are volatile in nature and aid in communication among insects. Based on the responses elicited pheromones can be classified as follow:

1. Sex pheromone: It is released by one sex only and trigger behaviour patterns in the other sex that facilitae in mating. In Lepidoptera, glands producing pheromones are located in the tip of the abdomen. Examples of female producing pheromones:
   Silkworm – Bombykol
   Gypsy moth – Gyplure, disparlure
   Pink bollworm – Gossyplure
   Cabbage looper – Looplure
   Tobacco cutworm – Spodolure, litlure
   Gram pod borer – Helilure
   Examples of male producing pheromones:
   Cotton boll weevil, *Anthonomous grandis*
   Mediterranean fruit fly, *Ceratis capitata*
2. Aggregation pheromone: These chemicals are released by individuals of one species that attract conspecific individuals to the source organisms.e.g.Females of bark beetle,*Dendroctonus frontalis* produce aggregation pheromone which attract both sexes. Similarly, males of phloem beetle, *Ips confuses* incorporate their pheromone in faecal matter which attract both sexes to the infested tree. some are:
   Dendroctonus frontalis – Frontalin
   Ips confuses – Ipsenol
   Periplanata Americana – Periplanone
   Tribolium confusum – Dimethyl decanol
3. Alarm Pheromone:
   Alarm Pheromones are chemical substances released by insects to warn members of the same species about the presence of or attack by an enemy.e.g.Dispersion or escape

in aphids and bugs. Aggresion in ants and soldier termites.Attraction in wasps and worker bees. Alarm Pheromones have been reported in hemiptera, isopteran and hymenoptera. Organs producing alarm pheromones are cornicles in aphids, Abdominal terga in dysdercus sp., cephalic glands in termites, sting glands in worker bees and anal,mandibular and dufour's gland in ants. The chemical nature of alarm Pheromones are terpenes (aphids), aldehydes (hemipterans) and formic acid (ants). They are low molecular weight compounds that spread rapidly but are short lived.

4. Trail pheromones: These pheromones are laid in form of intermittent or continuous lines on a soil substrate which trail follows perceive by their antenna to reach the destination which could be a mate or food source. Organs producing trail pheromones are sterna gland in termite. Dofour's gland, Poison gland, rectal gland and tibial glands in ants. Chemical nature of trail pheromones are caproic acid (*Zootermopsis* sp.), hexonoic, heptanoic, decenoic acids in forminine ants. Trail pheromones can be used to attract and kill ants. Trail pheromones mixed with bait can attract ants which when transport by ants to their nest kill all youngones.

Chitin systhesis inhibitors

A new class of insecticides was developed accidently when the insecticidal activity of benzoyl phenyl urea analogues was discovered. Benzoyl phenyl urea has the ability of inhibiting chitin synthesis in vivo by blocking the activity of the enzyme chitin synthetase. Two important compounds in this category are Diflubenzuron (Dimilin) and Penfluron. The effects they produce on insects include:

- Disruption of moulting
- Displacement of mandibles and labrum.
- Adult fails to emerge from pupal skin leading to death.
- Ovicidal effect.

Plumbagin is a naturally occurring chitin systhesis inhibitor present in the roots of a tropical medicinal shrub, *Plumbago capensis* and it inhibits ecdysis in several lepidopteran pests including *Helicoverpa* sp. and *Pectinophora gossypiella*.

RODENTICIDES

Chemicals used to control or kill rodents is called rodenticides.

1) **Single dose poison or acute poison :** e.g. Zinc phosphide

It is an inorganic stomach poison.In intestine it produces phosphine gas, which enters nervous system via blood.Symptoms of poisoning includes vomiting, weakening of heart activity, convulsion and death.It is available as Zintox.Pre-baiting should be done to overcome bait shyness(protective reflex reaction by which rats avoid poison baits).It is mixed with the food baits at the ratio of 1: 49, useful for field rodent control.

$$Zn_3P_2 + 6\,HCl \qquad 2\,PH_3 + 3\,Zn\,Cl_2$$

<u>Anti coagulants :</u>(Multidose poison or chronic poison): They are derivatives of coumarin compound sinterfere with systhesis and adsorption of vitamin K. As a result prothrombin formation and blood clotting are affected.In chonic level blood capillaries are damaged resulting in internal bleeding via oral, nasal, and anal openings.Finally death occurs due to blood loss.e.g. Warfarin (Rodaferin) :- mixed with food baits at the ratio of 1:19.

Bromodiolone : It is available as Moosh.Moosh is a ready to use anticoagulant cake.It is a single dose anticoagulant.Chronic poison results in profuse bleeding through ears and mouth.It is a second generation anticoagulant.

Acaricides: Chemicals used to control or kill mites.

Examples:

Diclofol – Analogue of DDT , available as Kelthare 18 EC.
Tetradifon – Organochlorine with sulphur, available as Tedion 8 EC.
Sulphur – Used against storage mite.
Ethion – OP compound, available as Tafethion, used for tea mite Control.

Nematicides:

These chemicals are used for controlling plant parasitic nematodes.

Some of the common nematicides are as follow:

1. **Dibromochloropropane (DBCP):** It is soil fumigant. It is markrted as Nemagon, \namafume and Memapaz. It is very effective against root-knot nematode, root lesion nematodes and cyst nematodes.
2. **Dichlropropane – dichlropropane(D-D mixture):** It is a mixture of 1,3- Dichlropropane and 1,2- Dichlropropane and is phytotoxic. It is a liquid fumigant and can be applied to the properly tilled soil by injecting it and lator plugging the holes.
3. **Ethylene dibromide:** It is a liquid fumigant and applied by injection method upto a depth of 15 cm in rows 25-40 cm apart.
4. **Carbofuran:** It is available in granular and flowable formulations under the commercial name Furadan. The recommended dose is 2-4 kg a.i./ha for the control of root-knot nematode and root lesion nematodes infesting vegetable crops.

Fumigants:

Fumigants are chemical which at a required temperatue and pressure can exist in the gaseous state in sufficient concentration to be lethal to a given organism.They can be applied in following way:-

i. Soil : To control the nematode in soil, the liquid fumigants are injected by using injecting gum.
ii. Storage : Liquid fumigants like Ethylene dibromide (EDB), methyl bromide(MB), carbon tetrachloride etc. and solid fumigants like aluminium phosphide are recommended in godowns to control stored product pest.

iii. Trunk : Aluminium phosphide ½ or 1 tablet is inserted into the affected portion of coconut tree and plugged with cement or mud for the control of red palm weevil.

Recent methods of pest control

Repellents: Chemicals that induce oriented movements in insects away from their source are called repellants. These may be unattractive and unpalatable.

Types of repellents:

A. Repellents of plant origin:

1. Commercial mosquito repellent like “odomas” uses citronella oil
2. Pyrethrum extracted from Chrysanthemum used against tsetse fly.

B. **Synthetic repellents :**

1. Dimethylpthalate - mosquito
2. Benzyl benzoate – mites
3. Bordeaux mixture – Phytophagous insects
4. Naphthalene – Fabric eaters
5. Smoke - Bees

Antifeedants

Antifeedants are chemicals that inhibit feeding in insects when applied on the foliage. Since insects do not feed on treated surface they die due to starvation.

Mode of action: Antifeedants inhibit the gustatory(taste)receptors of the mouth region and thusinsects fail to recognise the treated leaf as food. The insect slowly dies due to starvation.

Types of antifeedants:

a) Triazene : - AC 24055 – odourless, tasteless non-toxic chemical.
- Inhibit feeding in caterpillars, cockroaches and beetles.

b) Organotins : - Tri-phenyl tin acetate
- Against cotton leaf worm, Colarado potato beetle, caterpillars and grass hoppers

c) Carbamates : - Thiocarbamates and Phenyl carbamates
- Against caterpillars, Colarado potato beetle
- Baygon is a systemic antifeedant against cotton boll weevil.

d) Botanicals :

(i) Pyrethrum :- Extracted from flowers of *Chrysanthemum cinerarifolium*
- Acts as low doses against biting fly, *Glossina Sp.*

(ii) Neem : - Extracted from leaves and fruits of *Azadirachta indica*
- Against many chewing pests and desert locust.

Attractants

- Chemicals that cause insects to make oriented movements toward their source are called insect attractants.
- They influence both gustatory and olfactory recepters.

<u>**Types of Attractants :**</u>

- **Pheromones :**Chemical secreted into the external environment by an animal which elicit a specific reaction in a receiving individual of the same species.

- **Food lures:** Chemical present in plants that attract insect for feeding. They stimulate olfactory receptors.
- **Oviposition lures:** Chemicals that govern the selection of suitable sites for oviposition by insects.

e.g. Extracts of corn attracts H. armigera for egg laying on any treated surface.

Genetic Control

It involves transfer of genes from one species to other from one species to other by conventional breeding.

- The genes for resistance are transferred from a different species. E.g. WPH resistant gene has been transferred to Oryza sativa from O. officinalis.

Transgenic plants: These are plants which possess one or more additional genes. This is achieved by cloning additional genes into the plant genome by genetic engineering techniques.

- The added gene impart resistance to pests.
- E.g. Bt-endotoxin from *Bacillius thuringiensis* – The Gram positive bacteria *Bacillius thuringiensis* produces a crystal toxin called d(delta) endotoxin.
- The d- endotoxin is a stomach poison and kills the lepidopteran insects if consumed.
- The gene (DNA fragment) responsible for producing d endotoxin isolated from from Bt and cloned into plants like cotton, potato, maize etc. to produce transgenic plants.

Protese inhibitors (PI) genes :

- Insects have proteases in their gut which are enzymes helping in digestion of protein.
- Inhibit the proteases and affect digestion in insects.
- These genes are isolated from one plant and isolated into another to produce transgenic plants.
- E.g. cowpea trypsin inhibitor(CpTI) is a PI isolated from cowpea and cloned into tobacco which is resistant to *Heliothis virescens*

α- amylase inhibitor gene :

- α- amylase is a digestive enzyme present in insects for digestion of carbohydrate.
- α- amylase inhibitor affects digestion in insects.
- Transgenic tobacco and tomato expressing α- amylase inhibitor have been produced which are resistant to Lepidopteran pests.

Hormone

Hormones are substances that are formed in the endocrine glands and activate receptive cells when transported to them by body fluids.It plays role in growth and development.

1) **Brain hormone :**They are also called activation hormone(AH).

- Its role is to activate the corpora allata to produce juvenile hormone(JH).

2) **Juvenile hormone :** It is also called neotinin. It is secreted by corpora allata which are paired glands present behind insect brain. JH increases the larval instar when applied which may never pupate.

3) **Ecdysone :**It is also called moulting hormone. Ecdysone is a steroid and is secreted by prothoracic glands present near prothoracic spiracles. Moulting in insects is brought about only in the presence of ecdysone. Ecdysone hormone kill the insect when applied or may be brought in developing condition during wrong season, thus commiting ecological suicide.

Gamma Radiation

Radiation can be done by exposing g- radiation by ^{60}CO with its half life of 6 years is the most common method.G-radiation can produce the different types of sterility in insects.e.g. Infecundity, aspermia and inability to mate.

Insect	Stage	Dose
Housefly	2-3 days pupae	300 rads
Mosquito	Pupae	7700 rads
Screw worm	5 day pupae	2500 rads

Insecticides Act 1968-Important provisions

The Insecticides Act was passed by Parliament on September 2, 1968 to regulate the import, manufacture, sale, transport,distribution and use of insecticides with a view to prevent risks to human being or animals, and for matters connected therewith. The Act was enforced throughout the country on August 1, 1971 and the rules were framed thereunder on October 30, 1971. The various regulatory provisions made in the Act include compulsory registration, compulsory licensing, inspection, analysis of stocks, suspension and cancellation of licenses.

The enforcement of the Insecticides Act is the joint responsibility of the Central and State Government. The duties and responsibilities of both the Governments have been demarcated under the Act. Two statutory bodies namely the Central Insecticides Board and Registration Committee have been constituted under the Act.

Central Insecticides Board

Central Insecticides Board is headed by the Director General of Health Services, Government of India, and comprises 28 other members representing various disciplines in the field of agriculture, plant protection, health, ecology, forestry, transports, industry etc., of the Central Government, State Governments and Research Organisations. The functions of the Board include:

- To achieve the Central Government on the manufacture of insecticides under the industries Development Regulation Act, 1951.
- To specify the uses or classification of insecticides on the basis of their toxicity and their suitability for aerial application.
- To advise on tolerance limits for insecticides residues and establishment of minimum intervals between the application of insecticides and harvest in respect of various commodities.
- To specify the shelf life of insecticides.
- To suggest colourisation.

The Board consists of six expert panels to finalise the approved usage of different groups of insecticides.

- Panel on OP insecticides.
- Panel on Carbamates Insecticides.
- Panel on Chlorinated hydrocarbon Insecticides.
- Panel on fungicides.
- Panel on Herbicides and plant growth regulators.
- Panel on Fumigants and Rodenticides.

These panels finalises their recommendations which have been accepted by the Board and adopted by the Registration Committee. These panels have been accepted as standing Advisory Committees for finalising the new usage of insecticides based on published documents by the Agricultural Universities,ICAR institutions and manufacturers.

Registration Committee

The Central Government has constituted a Registration Committee comprising Deputy Director General (Crop Sciences), ICAR as the Chairman and 5 other members. The functions of the Committee include:

- To register insecticides after scrutinising their formula and verify their efficacy and safety to human beings and animals.
- To specify the precautions to be taken against poisoning.
- To carry out other incidental and consequential matters.

Registration of Insecticides

Every person who intends to impart or manufacture an insecticide has to obtain registration certificate from the Registration Committee. A separate registration certificate is required for each type of insecticides. The committee also approves the label and leaflet contain information. Three types of registration is available under the Act. **Provisional registration**, when the product is introduced for the first time in the country, for two years for data generation. Commercialisation is not allowed under this. **Regular or full registration** is granted when complete data has been generated to the satisfaction of the committee. **Repeat registration** is given for an already registered(Regular registration) product, for a subsequent applicant. Repeat registration is also full registration, but data requirement for this is very less.Other mportant authorities are:Licencing officers (State Government),Inspectors (Central and State Governments) and Analyst (Central and State Governments).

Application techniques of spray fluids

Pesticide Application Techniques

The methods used to apply agricultural chemicals on crops and herbicides on weeds or on soil, are known as application techniques. Appropriate dosage and even distribution of spray droplets on a target area are of paramount importance. Chemicals are used in doses ranging from 100 g or less to as high as a few L and kg ha- 1. Carriers or diluents are mixed with chemicals to ensure even distribution. The most important diluent- carrier is water. When used as a pesticide carrier, its volume should be varied with the method of application

Volume of water or any diluents carrier at flowering stage		
Volume	Field crops (L ha^{-1})	Trees and bushes (L ha^{-1})
High volume (HV)	>600	>1000
Medium volume (MV)	200-600	500-1000
Low volume (LV)	50-200	200-500
Very low volume (VLV)	5-50	50-200
Ultra low volume (ULV)	<5	<50

The efficacy of a pesticide in any application technique is mainly influenced by the following three factors:

- ✓ Mean level of deposit (dosage): This refers to the total amount of toxicant (active ingredient) used in treating a unit of the target area;
- ✓ Distribution of deposit: The surface of the leaf may be completely covered by a chemical (active ingredient) deposit in the case of runoff (high volume) spray, but the deposit may be unevenly distributed; and
- ✓ Wetting agents tend to decrease droplet size and increase spreads, and low-volatility carriers help prevent the evaporation of small droplets (low and ultra low volumes) and ensure better distribution.

Importance of Droplet Size
Droplet size plays a very important role in pesticide application by minimizing environmental contamination. Pesticide sprays are generally classified according to droplet size. When drift isto be minimized, a medium or coarse spray is required irrespective of the volume applied

Classification of sprays according to droplet size	
Vlume medium diameter of droplet (µm)^2	Classification of droplet size
<50	Aerosol
51-100	Mist
101-200	Fine spray
201-400	Medium spray
>400	Coarse spray

1. The most widely used parameter of droplet size is volume medium diameter (Vmd) which is measured in micrometers ((µm) 1 mic. = 1/1000 mm.

Different Types of Plant Protection Equipment Generally Used
• Hand sprayers and atomizers
• Hand compressed sprayers
• Knapsack sprayers
• Tractor-mounted sprayer
• Motorized knapsack mist blowers
• Ultra low volume or controlled-droplet applicators (ULV/CDA)
• Fogging machines/fogair sprayers
• Hand-carried dusters
• Hand-carried granule applicators
• Power dusters
• Aerial application (Aircraft sprayers)
• Injectors and fumigation equipment

Phytotoxicity of insecticides

The phytotoxicity of the insecticides was found to vary between years. Insecticidal soil treatments (granules and sprays) seemed to be as phytotoxic as seed coating. Synthetic pyrethroid seed coatings were slightly less phytotoxic than organophosphorus seed coatings.

Chlorinated hydrocarbon insecticides which are much used to control soil borne pests of horticultural and agricultural crops are very stable and persistent chemicals and when applied frequently may accumulate in soil.

The organophosphate insecticides, malathion,parathion and diazinon combined with bentazon caused severe injury to soybean (*Glycine max*) and navy bean (*Phaseolus vulgaris*).

Monouron, dimethylurea, uniformly applied to the soil surface immediately after planting was about twice to seedling cotton as was diuron. Phytotoxicity was increased when eitherof these herbicides was applied with either of the systemic insecticides, phorate, methyl phosphorodithiate. Most of the monoterpenoids were lethal to two spotted spider mite at high concentration. Monoterpenoids were phytotoxic to corn roots and leaves.

Symptoms of poisoning

Symptoms of poisoning of different insecticides are as follows:

Chlorinated hydrocarbon insecticides: They cause uneasiness, headache, nausea, vomiting, dizziness and tremors, convulsion, respiratory arrest, leucocytosis and rise in blood pressure.

Organophosphates insecticides:

They cause headache, giddiness, vertigo (whirling), weakness, excessive mucous discharge from nose and sense of tightness are symptoms of inhaled exposures. Blurring of vision, fixed pain point pupils and ocular pain occur when there is ocular exposure. Nausea followed by vomiting, abdominal contraction, diarrhoea and salivations are symptoms of ingestion. Loss of muscle coordination, speech defects, twitching of muscle, difficulty in breathing, hypertension, jerky movement, convulsions and coma indicates severeness of poisoning. Death may occur due to depression of respiratory centre.

Zinc phophide: It causes nausea, vomiting,diarrhoea, severe abdominal pain. On systemic toxic absorption,nausea, protracted vomimting and diarrhoea may occur which may be followed by haemorrhage in the skin, coma and damage to liver.

Mercurial fungicides: They cause nervous symptoms like paracenesthesia of tounge, lips and toes. Fine tremors and incordination, blisters on contacted skin.

Methyl bromide: dizziness and headache which followed by loss of appetite, nausea, vomiting, abdominal pain,blurred speech, blurring vision and temporary blindness. Mental confusion, tremors and convulsions may develop. The death may occur from respiratory complications.

Aluminium Phosphide: Headache, giddiness,nausea, diarrhoea and mental confusion. In case of delayed treatment, coma,loss of reflexes, death may ocur from respiratory or circulatory collapse.

Ethylene dibromide: Inhalation of gas may cause pulmonary lesions and pulmonary ocdema, respiratory and circulatory depressions occur. Damage to liver and kidney has been reported. Contact with liquid causes blisters on the skin if allowed to evaporate.

Carbamate: The symptoms of carbamate include headache, nausea,constriction of pupil of the eye, blurred vision, sweating, slow pulse rate, diarrhoea, muscular twitching, convulsion, coma, heart block.

Synthetic pyrethroids: Symptoms are facial sensation such as tingling, burning or numbness, irritation of oral and nasal mucosa, salivation and convulsive seizures.

First aid

Safety precaution should be taken when applying pesticides of categories. Improper handling of pesticides will result in fatality or lethal effect to human. Protective clothing rubber gloves, shoes and large handkerchief are very much essential to protect the body, hand, leg and face.

First aid should be given when a person using pesticide become ill. General symptoms of poisoning are headache, nausea, vomiting, anxiety and in severe cases convulsion occur. Immediate treatment such as washing the contaminated skin, fushing the contaminated eyes, artificial respiration and vomiting induced with saline solution must be employed for immediate recovery from poison. Immediate medical attention by a Doctor is essential. The Doctor must be informed the name of the pesticides and given as much information as possible so that he can administer effective antidotes for immediate recovery.

Awaiting the Doctor's arrival or till such time as the patient is taken to a hospital or dispensary, apply the following first aid methods:

1. In case of poisoning: It may be possible that inspite of observing all the precautions the workers may get poisoning. The treatments followed are:
   - (i) The effort should be made to remove the poison from the body of the affected person.
   - (ii) Antidotes should be administered as early as possible.
   - (iii) The excreta should be collected and sent for further examination.
   - (iv) Arrangement should be made to carry patient to hospital.
2. In case of swallowed the poison: In case of swallowed the poison efforts should be made for vomiting and stomach may be washed with stomsch tube. For inducing vomiting following substances may be given:
   - (i) Saline solution (15 g common salt in a glass of warm water).
   - (ii) One gram zinc sulphate in a glass of water.
   - (iii) Some quantity of soap glass of warm water.

   If the patient is unconscious then vomiting should be avoided and help of Doctor must be taken immediately.
3. In case of inhalation of poison: Following care should be taken in case of inhalation of poison:
   - (i) The patient must be brought immediately in open air.
   - (ii) The patient must be saved from cold and may be wrapped with blanket.
   - (iii) If the patient is feeling trouble in respiration, artificial oxygen may be employed.
   - (iv) The cloth of the body may be loosen.
   - (v) In case of headache, convulsion and fainting patient should be kept in dark place and avoid noise.
4. In case of skin contamination: It is just possible that the handling of pesticides some of the body may come in contact of poison. Under such circumstances following treatment may be followed:
   - (i) The contaminated parts may be washed with soap immediately.
   - (ii) The related part of the body should be washed with running water.
   - (iii) If necessary, Burnol may be used to avoid irritation.
5. In case of eye contamination: In case of eye contamination, hold the eyelids open, wash the gently with a stream of running water immediately. A delay of even a few seconds greatly increases the extent of injury. Continue washing until a physician arrives. Do not use chemical. They may aggrevate the injury.

Antidotes

Antidotes for treatment in pesticide poisoning

Antidote/Medicine	**Used in poisoning due to**
Common salt(Sodium chloride) Activated charcoal (7g) Magnesium oxide (3.5g)	Stomach poison in general
Tannic acid (3.5g) in warm water	Stomach poison in general
Gelatin 18 g in water or flour or milk powder or sodium thiosulphate	Stomach poison in general
Calcium gluconate	Chlorinated insecticide, CCl_4,Ethylene dichloride, Mercurial compound
Pentobarbital or azapam 5-10 mg intravenous administration	Stomach poison of Chlorinated hydrocarbon insecticide
Sodium bicarbonate	Stomach poison of Organophosphate compounds
Atropine sulphate (2-4 mg intramuscular/intravenous administration) or PAM	Organophosphate compounds
Atropine sulphate (2-4 mg intramuscular/intravenous administration)	Carbamates insecticides
Enobarbital,Diphenylhydration	Synthetic pyrethroids
Potassium permangnate	Nicotine, Zinc phosphide
Vitamin K_1 and K_2	Warfarin, Zinc phosphide
Methyl nitrite ampule	Cyanides
Etachlopramide (10mg) intravenous	Cyclodiene compounds

Part IV

Taxonomy: The science of classification.

Systematics: The science of study of kind and diversity of organisms. It includes taxonomy and evolution.

Binomial nomenclature: The system of naming organisms using two words is called Binomial nomenclature. First name is the generic name and second name is the species name. First letter of generic name is wtten in capital and first letter of species and subspecies are in small letter. All the words are italicised and written in italics or it is written and underlined separately. The auther name is written after the species name. The author name is placed in bracket. E. g. Gram pod borer, *Helicoverpa armigera* (Hubner).

Species: It is a group of individuals having similar structure, development and behaviour which interbred to produce viable offsprings.

Subspecies: A taxonomic category below the level of species. Subspecies is the geographic variety or race.

Biotype: A genetically distinct strain or subgroup of a species distinguished by some behavioural or physiological difference but indistinguishable morphologically.

Genus: A group of species combine to form a genus. Two or more species agreeing in many important features are included into a genus.

Family: Genera having common characters constitute a family.

Order: Two or more families having common characters are placed in an order.

CLASSIFICATION OF CLASS INSECTA

The class Insecta has two subclasses viz., Aperygota and Pterygota.

Aperygota	Pterygota
Wingless	Winged
Metamorphosis is absent or slight	Present
Mandibular articulation is monocondylic i.e.single	Dicondylic i.e. double
Pregenital abdominal appendages present	Absent

The subclass Apterygota has 4 orders:

1. Thysanura – Silverfish
2. Collembola – Spring tail or snowflea
3. Protura – Telsontail or proturans

4. Diplura – Diplurans or japygids

The subclass Pterygota has two divisions viz., exopterygota and endopterygota.

Exopterygota	Endopterygota
Wing development external	internal
Metamorphosis Incomplete (Hemimetabolous or gradual, paurametabolous)	Complete (Holometabolous)
Pupal stage absent	present
Immature stage is called nymph or naiad and resemble with adult	Larva and different from adult

The class Insecta is divided into 29 ordres (4 in Apterygota and 25 in Pterygota).

A New insect order is Mantophasmatodea i. e. 30 th order.e.g. Gladiator. It resembles as a cross between a stick insect, a mantid and a grasshopper.

Exopterygota:

1. Ephemeroptera – Mayflies
2. Odonata – Dragonfly, Damselfly
3. Plecoptera – Stonefly
4. Grylloblatodea – Grylloblata
5. Orthoptera – Grasshopper, locust, cricket, mole cricket
6. Phasmida – Stick insect, leaf insect
7. Dermaptera – Earwigs
8. Embioptera – Embids/ Webspinners
9. Dictyoptera – cockroach, preying mantis
10. Isoptera – Termites
11. Zoraptera – Zorapterans, Zorotyphus
12. Psocoptera – Book lice
13. Mallophaga – Bird lice
14. Siphonculata - Head and body louse
15. Hemipetra - Bugs
16. Thysanoptera – Thrips

Endopterygota:

1. Neuroptera – Antlions, aphidlions, owl flies, mantispid flies
2. Mecoptera – Scorpionflies
3. Lepidoptera – Butterflies and moths
4. Trichoptera – Caddisfly
5. Diptera – True fly
6. Siphonaptera – Fleas
7. Hymenoptera – Bees, wasps, ants
8. Coleoptera – Beetles and weevils

9. Strepsiptera - Stylopids

Chapter XX INSECT FAMILIES – IMPORTANT CHARACTERS

Oder - Orthoptera: Characters: Medium to large sized insects. Antenna is filiform. Prothorax is large. Pronotum curved. Hind legs are saltatorial. Forewings are leathery known as tegmina. Ovipositor well developed.

Family – Acrididae: Short horned grasshoppers and locusts. Antenna is short. Tarsus three segmented. A row of peg like projections found on hind femur. Ovipositor – short.

Tettigonidae: Long horned grasshoppers, Katydids and bush crickets. Antenna is long, slender as long as or longer than the body. Tarsus is four segmented. Ovipositor is sword like. Auditory organs are found in foretibiae. In each foretibia a pair of tympanum is present. Sound production is alary type.A thick region on the hind margin of the forewing(scraper) is rubbed against a row of teeth on the stridulatorial vein (file) present on the ventral side of another forewing which throws the resonsnt area on the wing (mirrors) into vibrations to produce sound.

Gryllidae: Crickets, Antenna is long. Tarsus is four segmented. Ovipositor is slender and needle like. Cerci are long and unsegmented. Auditory organs and stridulatorial organs are similar to long horned grasshopper. *Gryllus* sp.is household pest and cause sound and nuisance during night.

Gryllotalpidae: Mole cricket. They are brown coloured insects found inside the burrows. \eyes are reduced. Pronotum is elongated, ovate and rounded posteriorly. Foreleggs are fossorial. Tibiae are expanded and digitate. A humming sound is produced by rubbing the forewings. A pair of tympanum is found on the under surface of the tibiae. Ovipositor is vestigeal. Stridulatorial structures are absent.

Dictyoptera: Haed is hypognathous. Antenna is filiform. Mouthparts are chewing type. Tarsus is five segmented. Forewings are tegmen. Hindwings are membranous and folded fanlike. Eggs contained in an ootheca.

Family – Mantidae: e.g. preying mantis. Pronotum is elongate and does not cover the head. Forelegs are raptorial.Carnivorous. They are predators on moths, flies, grasshoppers, caterpillers etc. Hence they are beneficial.

Blattidae: Cockroaches. Head is hidden by the pronotum.Pronotum is shield like. Legs are cursorial. Gizzard ispowerfully armed with chitinous teeth to grind food. Omnivorous. Eggs are laid inside a chitinous ootheca.

Odonata: Dragonflies and damsel flies. Medium to large sized insects. Head is globular and constricted behind into a petiolate neck. Compound eyes are large. Three ocelli . Mouthparts are adapted for biting. Wings are membranous with many crossveins. Wings have a dark pterostigma towards the costal apex. Spinous femora

and tibiae are useful for holding the prey. Legs are held in such a aaaaaaaway that a basket is formed into which the food is scooped. Abdomen is long and slender.Adults are aerial predators.Naiads are aquatic predators.

Order – Isoptera (Family- Termitidae): e.g. termites and white ants. They are greyish white, soft bodied insects. Compound eyes are presnt in alate forms and usually absent in apterous forms. Antennae are moniliform. Wings are membranous. They are social insects living in a colony. Soil inhabiting termites construct earthen mounds called termitaria. Four distinct castes in a termite colony viz., King, queen, workers and soldiers. The lower termites depends on flagellate protozoans in the digestion of cellulose. In higher termites, fungus and bacteria helps in the digestion of cellulose.

Thysanoptera (Family - Thripidae):e.g. thrips. They are minute, slender, soft bodied insects. Mouth parts are rasping and sucking. There are three stylets and right mandible is absent. Wings are either absent or long, narrow and fringed with hairs. Tarsus is with one or two segments. Abdomen is pointed. They suck the plant sap. Some are vectors of plant disease.

Order- Hemiptera: head is opisthognathous. Mouth parts are piercing and sucking type. Two pairs of bristle like stylets which are modified mandibles and maxillae. Forewings are either thickened or basally coriaceous and distally membranous. Mesothorax is represented dorsally by scutellum. Two suborders are:

Sub order – Heteroptera: Head is horizontal. Scutellum is present. Forewings are hemelytra. No honey dew secretion. Herbivorous, predaceous or blood sucking. Important families are:

Pentatomidae: (stink bugs or shield bugs): Antenna is five segmented. Scutellum is prominent and shield like. Adults and nymphs produce a disagreeable odour from stink glands located in metathorax and abdomen respectively. Some are phytophagous and some are predaceous.

Coreidae: (Squash bug or leaf footed bugs). Wings membranous with many branching veins. Stink glands are found inside the metathorax. The emit a bad odour. Hind tibia and tarsi are expanded leaf like.

Cimicidae: Bed bugs. Body is dorsoventrally flattened so that they can hide in cracks and crevices. Body is oval and dull reddish brown in colour. Stinck glands are locatedin the dorsal surface of first three abdominal segments. They are blood sucking ectoparasites on birds and mammals. *Cimex lectularis* and *Cimex hemipterus* are two important species affecting man in temperate and tropical conditions respectively.

Pyrrhocoridae: (Red cotton bugs) Elongate , oval bugs. They are marked with red and black.Feeding injury caused by these bugs leads to the contamination by the fungus.

Lygaeidae: (Seed bugs or chinch bugs) Cuneus is absent in hemelytra. Membrane has a few irregular veins(4-5 veins).

Sub order – Homoptera: Head is deflexed. Forewings are of uniform texture. Herbivorous. Scutellum not well developed. Honey dew secretion. Important families are:

Cicadellidae: (Leaf hoppers or jassids). Elongate with a wedge shaped body.Hind tibiae have a double row of spines. Ovipositor is well suited for lacerating the plant tissue. Nymphs and adults have the habit of running sidewise. They suck the plant sap and transmit diseases e.g. green leaf hopper, *Nephotettix virescens*. It transmit tungro disease in rice.

Delphacidae: (plant hoppers) large mobile flattened spur is present at the apex of hind tibia. It causes hopper burn, transmits viral diseases in rice.e. g. Brown plant hopper (BPH), *Nilapravata lugens*.

Aphididae: (Aphids or plant lice or greenflies) body is pear shaped. Both alate and apterous forms are found. A pair of cornicles or wax tubes is present in the dorsum of fifth or sixth abdominal segments which secretes wax like substance. They excrete copious amount of honey dew on which ants feed and sooty mould fungus grows. Parthenogenetic reproduction. They feed on plant sap and disseminate plant diseases e.g. Cotton aphids, *Aphis gossypii.*

Coccidae: (Scale insect or soft insects) Male insects are gnat like, with long antennae, lateral eye and vestigial mouth parts. Mesothorax is enlarged bearing one pair of wings with one or two veins. Hind wings are halteres. Female body is covered with a wax coating. They are wingless, legless insects and suck the plant sap.

Aleyrodidae: (Whiteflies) Minute insects which superficially resemble tiny moths. Wings are opaque and dusted with mealy white powdery wax. The anus opens at the base of the lingula (tongue like organ) through which honey dew is excreted in large amount. It transmits vein clearing disease in bhindi.e.g. Cotton whitefly, *Bemisia tabaci.*

Pseudococcidae: (Mealy bugs) elongate body, covered by long radiating thread of mealy secretion. Wings are absent. Both nymph and adult suck the sap.

Lophophidae:e.g. Sugacane leaf hopper (*Pyrilla perpusilla*). Haed is produced into a snout. Hind trochanter ia directed backward. Hind basitarsus is moderately long. Both nymphs and adults suck the sap and reduce the quality and quantity of cane juice.

Order- Neuroptera: Soft bodied insects. Antenna is filiform. Mouthparts are chewing type in adults. Wings are eual, membranous with many cross veins. They are weak fliers. Larva is campodeiform with mandibulosuctorial mouthparts.Pupa is exarate.**Family Chrysopidae:** (Green lacewings, aphidlions, golden eyes) Body is pale green. Eyes are golden yellow. Eggs are mounted on stalks to avoid predation and cannibalism. Larvae prey on soft bodied insects especially on aphids. They are mass multiplied and released in fields for controlling aphids.

Lepidoptera: Body, wings, appendages are densely clothed with overlapping scales which give colour, rigidity and strength. Mouthparts are siphoning type. Frenate or amplexiform type of wing coupling is found. Larvae are polypod- eruciform type. 2-5 pairs of prolegs are found in the abdomen. Pupa is generally obtect. It is either naked or enclosed in a cocoon made out of soil, frass, silk or larval hairs. The families are:

Pieridae: e.g. Daincha caterpillar (*Eurema hecaba*). They are white or yellow or orange coloured with black markings.Larva is green, elongate and covered with fine hairs.

Papilionidae: e. g. Citrus butterfly (*Papilio demoleus*). They are large and bright colored. Prothoracic legs have tibial epiphysis. In many species hind wings have tail like prolongation. Amplexiform type of wing coupling is present. Larval body is either smooth or with tubercles. Retractile osmeteria are present on the prothoracic tergum of the caterpillar.

Noctuidae: (Moths like gram pod borer (*Helicoverpa armigera)* They are medium sized, stout moths, nocturnal. Some larvae are semiloopers. They have either three or four pairs of prolegs. They attack the plant at night. Some lavae like cutworm larvae cut the seedlings close to the ground.

Sphingidae: (Hawk moth, sphinx moth, Horn worms) They are large sized stout moths and powerful fliers. Proboscis is very long. Forewings are elongated and pointed. Hindwings are reduced in width fitting into the indented margin of forewings.Larva is smooth with a mid-dorsal horn (anal horn) on eighth abdominal segment. Pupation takes place in earthen cells.

Pyralidae: Proboscis is vestigial in many species. Labial palp is snout like. Larval varies in habits. It may bore the stem or remain in silken web among spun up plants parts. Some larvae are aquatic and gill breathing. E.g. rice stem borer, *Scirpophaga incertulas.*

Gelechidae: Forewings trapezoidal and narrower than hindwings. Caterpiller bore into the seeds, tubers and leaves. E.g. Cotton pink bollworm, *Pectinophora gossypiella.*

Arctiidae: (Tiger moth) Wings are spotted or banded, nocturnal. Larva is either sparsly hairy or densely hairy. Black hairy caterpillar.

Saturnidae: e.g. Giant silkworm moth. They are large sized moths. Antenna is bipectinate. Transparent eye spots. Are present near the centre of each wing. Larva is stout and smooth. Cocoon is dense and firm. e.g.Tassar silk worm moth, *Antherea paphia*.

Bombycidae: e.g. Mulberry silk worm, *Bombyx mori*. Antenna is bipectinate. Larva is either with tuft hairs or glabrous with medio dorsal horn on the eighth abdominal segment. Pupation occurs in dense silken cocoon.

Order - Coleoptera: They are minute to large sized insects. Antenna is usually 11 segmented. Mouthparts are chewing type. Forewings are heavily sclerotised (elytra), veinless and hardened and not used for flight. It covers the hindwings and abdomen.Hindwings are membranous with few veins. A small scutellum remains exposed as a little triangle between the bases of elytra. Larvae are called **grubs**. Pupae are usually exarate. Different families are:

Coccinellidae: (Lady bird beetle) They are hemispherical, convex above and flat below. Head is small, turned downward and a prominent prothorax.Elytra is convex. Grub is compeiform and spiny. Except the genus *Epilachna*, others are predators on aphids, scales, mites and white flies.

Chrysomelidae: (rice hispa, cabbage flea beetle) Body is elongate, narrow in front but broad distally, round at the anal end. Grub generally feed on roots of plants. It pupates in earthen cell.

Cerambycidae: (Longhorn beetle) Body is cylindrical. Compound eyes are notched. Antennae are as long or longer than the beetle itsel and it acn be flexed backward. Grubs rare called round headed borers. They develop beneath the bark and tunnel into the branches or main stem..e.g. Mango stem borer, *Batocera rufomaculata*.

Curculionidae: (weevils or snout beetles) Minute to large sized body. Frons and vertex of the head are produced inti snout. Antenna is geniculate and found usually in the middle of the snout. Grubs are apodous and eucephalous. Weevils are important crop pests occurring both in field and storage. E.g. Coconut red palm weevil.

Bruchidae: (Pulse beetle) They are small, short and snout is blunt. Antenna is serrate. Hind femur is thick. Elytra are short and do not cover tha abdomen. The exposed part of the abdomen is called as pigidium. Eggs are whitish, scale like and glued to the pods or seeds by a glutinous secretion. Pupation occurs within the seed. Adult emerges by cutting a circular hole.

Scarabaeidae: (Scarabs, Dung beetles) Head is broad and flat. Mandibles are membranous and incapable of chewing. Spines and horns on head and prothorax. Forelegs are fossorial. Adults and larvae are scavengers. They feed upon the droppings of animals and role on the dung into balls and bury them in underground chambers. They use their head and forelegs for handling dung and digging pits in the soil. Head is used as an excavator and fore tibia as shovel.

Order – Hymenoptera: Mouthpatrs are primarily adapted for chewing. Both prothorax and metathorax are fused with mesothorax. Wings are stiff and membranous. Forewings are larger than hindwings. Wing coupling is hamuli.The first abdominal segment is called propodeum. It is fused with metathorax. The second segment is known as pedicel which connects the thorax and abdomen. Abdomen beyond the pedicel is called gaster or metasoma. Ovipositor is always present in females. Grub is apodous and eucephalous. Pupa is exarate. Different families are:

Tenthridinidae: e.g. Saw flies, *Athalia lugens proxima*. They are wasp like. Abdomen is broadly joined to the thorax. Ovipositor is saw toothed and suited for slicing the plant tissue. Larva is eruciform. It has a pair of ocelli, papillae, three pair of thoracic legs and 6-8 pairs abdominal legs. Prolegs lack crochets. They are external feeders on foliage.

Apidae: (Honey bees) Body is covered with branching hairs. Mouth parts are chewing and lapping type. Mandibles are suited for crushing and shaping wax for building combs. Legs are specialized for pollen collection. Scopa (pollen basket) is present on hind tibia. Social insects with three castes viz., queen, drone and workers. Indian honey bee, *Apis indica* and Italian honey bee, *Apis mellifera* are domesticated. Italian honey bee, *Apis mellifera is domesticated on commercial scale.*

Trichogrammatidae: (Egg parasitoids) They are very tiny insects(0.3 to 1.0 mm long). Tarsus is three segmented. Forewing is broad with pubescence (microscopic hairs) in rows. Forewing is reduced and fringed with hairs. e. g. Trichogramma sp. is extensively used in the biological control of sugarcane moth borers.

Ichneumonidae: (Ichneumonflies) Adults are diurnal and visit flowers. Trochanter is two segmented. Hind femur is with trochantellus. Forewing has two recurrent veins. Ovipositor is arising anterior to the tip of abdomen. Larvae are mostly parasites.They spins cocoons in or outside the host.

Braconidae: (Braconid wasps They are small ,stout bodied insects. Forewing has one recurrent vein. Gaster is sessile or subsessile.They parasitise lepidopteran larvae commonly.Pupation occurs in silken cocoons either externally on the host or away from the host in groups. *Bracon brevicornis* is mass multiplied and released for the control of coconut black headed caterpillar.

Chalcidae: e.g. Chalcid wasps. Hind coxae are five to six times larger than fore coxae. Hind tibial spurs are larger than mid tibial spurs. Hind femora are larger with a row of short teeth beneath. Wing venation is reduced to a single anterior vein. Ovipositor is short and straight.

Diptrea: Small to medium sized, soft bodied insects.A single pair of wing. Hind wing modified into haltere. Larvae are known as **maggots**. They are apodous and acephalous. Pupa belongs to the coarctate type.The families are:

Cecidomyiidae: (Gall midge) They are minute delicate, mosquito like flies. Antennae and legs are long. Wing venation is reduced and covered with long hairs. A dark sclerotized area is present midventrally on the prothorax in the larva called 'chest bone'. Rice gall midge: Orseolia oryzae. Larval feeding produces galls.

Tephritidae: (Fruit flies) Subcosta bends apically and fades out. Wings are spotted or banded. Female has a sharp and projecting ovipositor. They are highly destructive to fruits and vegetables. E. g. Cucurbit fruit fly, *Dacus cucurbitae*.

Tachinidae: (Tachinid flies) Arista is completely bare. Abdomen is stout with several bristles. They are non specific endoparasites on the larvae and pupae of Orthoptera, Hemiptera, Lepidoptera and Coleoptera.

Agromyzidae: (Leaf-miner flies, pod flies and stem flies) These flies are small, blackish or yellowish. The larvae are leaf miners or stem borers or pod eaters. Most agromyzids make serpentine mines.

Culicidae: e.g. Mosquitoes. They are delicate, fragile, slender insects. Females have piercing and sucking type of mouth parts with six stylets. Antenna is plumose in male and pilose in female.. Legs are slender, delicate and long. Wings are fringed with hairs and scales on hind margin and on some veins. Larvae are called **wrigglers**. Larval head is large with chewing type of mouth parts and having respiratory siphon on penultimate abdominal segments.Pupa is known as **tumbler**. It is very active. It has a pair of prothoracic horns which houses the anterior pair of spiracles.

Muscidae: e.g. House fly. Antenna is aristate. Mouth parts are sponging type. Pretarsus consists of two claws and two adhesive pads. First abdominal segment is yellow. Maggots are scavengers. Adults carry certain disease causing microbs on its legs, body hairs and mouth parts.